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Aviation and ground systems must increase use of emerging and advanced technologies to remain viable in complex, future battlefield environments. Unmanned vehicles will become part of future military operations due to: the demand for immediate intelligence on the battlefield, decreasing defense budgets, increasing operational tempos, and the low tolerance for casualties by the public. This work develops and evaluates system level concepts that fulfill these overall requirements using an unmanned hybrid vehicle. The unmanned hybrid vehicle combines the attributes of an autonomous vertical takeoff and landing air vehicle and an autonomous ground vehicle. This allows fast, flexible deployment and quiet, longer duration ground missions. The assumed time of deployment is the year 2012. The study included requirements definition, concept synthesis, and down selection to three final configurations. Engineering students from the University of Alabama in Huntsville and Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile participated on three competing design teams. Team 1 developed a basic system with coaxial rotors and a fuel cell drive system. The system is one unit that can both fly and operate on the ground. Team 2 developed a separate air and ground vehicle with intermeshing rotors. The integrated ground unit is deployed and retrieved by the air system. Team 3 also developed a separate air and ground vehicle but with a single rotor system that also requires a tail rotor.

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Unnamed Hybrid Vehicle

FINAL REPORT – VOLUME I
SUMMARY

Submitted By:

UAH Integrated Product Team 2002

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ABSTRACT

Aviation and ground systems must increase use of emerging and advanced technologies to remain viable in complex, future battlefield environments. Unmanned vehicles will become part of future military operations due to: the demand for immediate intelligence on the battlefield, decreasing defense budgets, increasing operational tempos, and the low tolerance for casualties by the public. This work develops and evaluates system level concepts that fulfill these overall requirements using an unmanned hybrid vehicle. The unmanned hybrid vehicle combines the attributes of an autonomous vertical takeoff and landing air vehicle and an autonomous ground vehicle. This allows fast, flexible deployment and quiet, longer duration ground missions. The assumed time of deployment is the year 2012. The study included requirements definition, concept synthesis, and down selection to three final configurations. Engineering students from the University of Alabama in Huntsville and Ecole Supérieure des Techniques Aéronautiques et de Construction Automobile participated on three competing design teams. Team 1 developed a basic system with coaxial rotors and a fuel cell drive system. The system is one unit that can both fly and operate on the ground. Team 2 developed a separate air and ground vehicle with intermeshing rotors. The integrated ground unit is deployed and retrieved by the air system. Team 3 also developed a separate air and ground vehicle but with a single rotor system that also requires a tail rotor. A review team consisting of government and industry professionals ranked the final proposals and selected the Team 3 concept as the best proposal. An overview of the requirements, design alternatives, and the final design is given in this report. The report also presents a verification of the selected concept with recommendations for future refinements. The concept of deploying an Unmanned Hybrid System of this type by 2012 appears to be technically feasible. Because most of the technologies are available, the key challenges are the programmatic issues related to integrating and testing the system in the immediate future so that it could meet 2012 initial operational capability.

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NOMENCLATURE

AMCOM	US Army Aviation and Missile Command
BDA	Battlefield Damage Assessment
BLOS	Beyond Line of Sight
CCD	Charge Coupled Device
CDD	Concept Description Document
CDL	Common Data Link
CPU	Central Processing Unit
DGPS	Differential Global Positioning System
ESTACA	Ecole Superieure des Techniques Aeronautiques et de Construction Automobile
FADEC	Full Authority Digital Engine Control
FLAPS	Fluorescent Aerodynamic Particle Sizer
FLIR	Forward Looking Infra-red
FLOT	Forward Line of Troops
GPS	Global Positioning System
HMMWV	High Mobility Multipurpose Wheeled Vehicle
ICE	Internal Combustion Engines
IFF	Identify Friend or Foe
IPT	Integrated Product Team
IR	Infrared
LED	Light Emitting Diode
LOS	Line of Sight
MIAG	Modular Integrated Avionics Group
PEM	Proton Exchange Membrane
RISTA	Reconnaissance, Intelligence, Surveillance, and Target Acquisition
RVM	Reconfigurable Vision Machine
SAR	Synthetic Aperture Radar
SATCOM	Satellite Communication
UAH	University of Alabama in Huntsville
UAV	Unmanned Aerial Vehicle
UGV	Unmanned Ground Vehicle
UHV	Unmanned Hybrid Vehicle
VROC	Vertical Rate of Climb

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1.0 INTRODUCTION

The U.S. Aviation and Missile Command, Advanced Systems Concepts Directorate (AMSAM-RD-AS) at Redstone Arsenal, Alabama funded this study with the University of Alabama in Huntsville, Huntsville, Alabama. James P. Winkeler served as the AMCOM technical monitors for the project. Robert A. Frederick, Jr. acted as the UAH Principal Investigator. The final report is submitted in four volumes. Volume 1 summarizes the work performed on the project. The appendix material in Volume 1 contains the Concept Description Document, Baseline Presentation Charts, and Review Team Information. Volumes 2, 3, and 4 each describe the final concept developed by each integrated product teams. Appendix material in Volumes 2, 3 and 4 contain supporting calculations, White Papers, and links to web pages. The technical results[1] of this project and the international team aspects[2] are also explained in AIAA Conference Papers. A CD-ROM was also provided to the customer that contains video of the mentor lectures.

1.1 UAH IPT Project Background

The University of Alabama in Huntsville (UAH) has established an Integrated Product Team (IPT) project to better introduce students to a teamwork environment. The IPT project uses industrial mentors[3, 4] to guide teams of engineering[5], business[6], and liberal arts[7] students in a competitive design project.[8] Past projects have included a hybrid rocket sub-orbital vehicle,[9] a tactical missile,[10] a maglev train, a rocket-launched glider, two advanced rotorcraft projects,[11] a crew transport/recovery vehicle for the International Space Station,[12] and an unmanned air-ground vehicle.[13] Details of these projects can also be found at the www.eb.uah.edu/ipt web page.

1.2 UHV Project Introduction

The IPT 2002 project was to design an Unmanned Hybrid Vehicle (UHV). The project is a parallel research/education effort sponsored by the U.S. Army Aviation and Missile Command. Three international teams of undergraduate students competed to present the best configuration of a UHV. The teams consisted of mechanical, aerospace, electrical, computer and industrial engineers from the University of Alabama in Huntsville. They also included engineering students from ESTACA, a college in France.

The IPT project begins with a series of leadership development lectures and meetings among the team leaders. Students learn skills required to lead and manage a large integrated product team. A notional Concept Description Document that details the requirements for the system is developed in conjunction with a "customer." The next semester three IPTs are formed. Nineteen seniors from the UAH Department of Mechanical and Aerospace Engineering, nine fourth-year students from ESTACA, and six students from the UAH Department of Electrical and Computer Engineering were distributed among the three teams.

In Phase 1 of the project all three teams work together to configure a baseline vehicle that attempts to fulfill the project requirements using existing technology. An eight-hour technical symposium is held in which industry mentors brief the students on the technical disciplines for the project and show one iteration of the design process. During this phase an assessment of existing vehicles is also made to see how many of the requirements they can meet. This establishes the deficiencies of current technologies and allows the mentors to interact with the students. At the end of this phase, the class briefs a Review Team consisting of government and industry professionals. The entire team presents the baseline concept and recommendations for final revisions to the Concept Description Document.

For Phase 2, the three individual IPTs now compete to synthesize alternative configurations to the baseline. The teams each synthesize three very different configurations to look at a wide range of possible configurations. At the end of this phase each IPT produces a written White Paper and makes a private poster presentation to the Review Team. They present a description of each concept and an evaluation matrix that shows their assessment of each configuration's attributes relative to the Concept Description Document. Each team uses this assessment and feedback from the Review Team to select one of their concepts for refinement in Phase 3.

In Phase 3, each team refines their selected concept. This involves making estimates of weight, range, and operating characteristics of their system using first-order mission simulations. The system engineers integrate aerodynamics, propulsion, ground robotics, structures, avionics, sensors, and flight controls into their configurations. They also developed an outline of programmatic information including a development schedule, project costs, and project production. This information is documented by each IPT in a 50-page proposal.

To rank the three concepts, each IPT makes a 20-minute presentation to the Review Team. The Review Team asks questions based on a written proposal and the oral presentation. Each reviewer ranks the proposals based on criteria adapted from the AIAA Design Competitions. The Review Team Chairman then compiles the results and makes the ranking. Representatives from each team are then invited to present their work at a symposium in France.

2.0 PROJECT REQUIREMENTS

2.1 The Needs

Unmanned vehicles will play an extensive role in 21st century war fighting. Information dominance will be the key to success for our military forces. War fighters have voiced the need for situational awareness, target identification, dominant battlefield awareness, dominant battle space knowledge, and information superiority for many years. Unmanned air/ground vehicles can make this a reality.

Advances in technology, greater acceptance and high profile demonstrations of capabilities have resulted in broad support for and increased interest in unmanned systems. Funding has increased, new program starts are occurring with greater frequency and proponents at the highest levels of government are speaking out in favor of unmanned technologies.

Recent world events have rapidly accelerated the need for capabilities provided by unmanned systems. The UHV is intended for use at the battalion level to assist medium and light forces and increase their effectiveness. These technologies add new strength to worldwide missions while reducing high-risk or even lethal exposure to personnel.

Robotic platforms are essential to penetrate physically prohibitive areas and even serve as an extension of the human soldier. Robots can deploy rapidly to the point of interest and can augment the power of the troops by performing multiple missions without the risk to human life.

These devices also help the military deal with manpower cutbacks and allow troops to have more eyes and ears across the battlefield.

The US Army Aviation and Missile Command (AMCOM) have specified these needs. Reconnaissance missions performed by soldiers on the forward line of troops (FLOT) are extremely dangerous, and are impossible beyond line of sight (BLOS). The UHV will allow the FLOT to make more informed and better decisions by enhancing the reconnaissance, intelligence, surveillance, and target acquisition (RISTA) capability of their respective battalions. AMCOM must incorporate these technologies to remain viable in the battlefield.

2.2 The Requirements

The US Army Aviation and Missile Command requested that IPT 2002 develop a vehicle that integrates both a UAV and UGV to perform missions normally performed by soldiers in the battlefield. AMCOM first presented us with the Concept Description Document, which lays out the notional requirements for this type of operational capability. This need calls for an intelligent and autonomous vehicle that is capable of performing a preplanned or diverted duty. It must have maximum survivability and must be capable of keeping up with the operational tempo. It must enhance the RISTA and battlefield damage assessment (BDA).

It must also meet the mission/payload requirements. This involves being able to fly to operational range, which is 15-30 km ahead of the fighting force, in 30 minutes or less while flying nap of the earth, which makes it capable of operation under and detection of battlefield obscurants. Upon reaching this site, while transporting critical payloads between 60 and 120 lbs, the vehicle will land and drop off the payload. When this mission is complete, the UHV will then return to the launch area.

The UHV requirements are the actual performance characteristics that the vehicle must meet to perform the mission. This includes flying between 30 and 100 km/hr with a vertical rate of climb (VROC) of no less than 200 ft/min. This VROC will enable the UHV to fly in a nap of the earth configuration and the capability to take evasive action if necessary. It shall also be capable of landing on unimproved roads at a ground speed of no less than 6 km/hr at a radius between 0.5 and 1 km at a grade of no more than 12 degrees.

Some of the key challenges of this type of system are technologically and integration based. This type of system must be intelligent in order for it to monitor, think, and react to a situation. Artificial intelligence is constantly evolving. We are constantly learning new ways to build working systems that extend and test ideas. Also, tying in capabilities of a system with both an air and ground unit together has a big issue with weight. Most propulsion systems are bulky and have high specific fuel consumption. Also reducing the weight with lighter and stronger materials along with a high efficiency engine is the challenge and the future of this vehicle. Table 1 summarizes the key features of the detailed Concept Description Document found in Appendix A.

Table 1 UHV Concept Description Document Summary

CDD Requirement	Requirement	Need Addressed
Range from launch point	15 km	Providing BLOS Capability
Cruise Speed	30 km/hr	Keeping Operational Tempo
VROC	200 ft/min	Operating NOE, in winds, and over obstacles
VTOL Capability	Yes	Enabling takeoff and landing on unprepared surfaces
Payload:	60 lb	Accommodating sensor packages
Operational Altitude	0 to 500 ft AGL	Providing survivability
Hover to full flight profile	Yes	
Operation	Autonomous or Semi-autonomous	Providing force multiplication
Acoustic Signature	Near Quiet	Ensuring survivability
Communications	BLOS	Enabling RISTA
Deployment	2012	Providing force multiplication

3.0 THE BASELINE CONCEPT

The Baseline Design established the limitations of existing technologies in meeting the project requirements. Figure 1 is an artist rendering of the "Rolling Feather." The Rolling Feather utilizes a coaxial rotor system powered by a 125 hp IO-240 engine.[14] The design is capable of 500 fpm VROC, and utilizes AV fuel. The power to hover at 4000 ft and 95°F is 87 hp and the cruising power is 53 hp. The radius of the rotor disk is estimated at 7.2 ft, with a disk loading of 9.21 lb_f/ft^2. The ground mission segment is accommodated by four wheel electric motors powered by six, six-volt batteries. The system is capable of carrying a 60 lb payload with a weight estimated at 1500 lbs. The primary BLOS method is ground radio communication and the navigation method utilized is GPS. The primary sensor enabling the Rolling Feather to relay information is FLIR Camera. The issues raised by the baseline design were: the need for more refined weight analysis, the need for an engine that would operate on heavy fuels, and the need for integration of the sensors and flight avionics to perform autonomous missions.

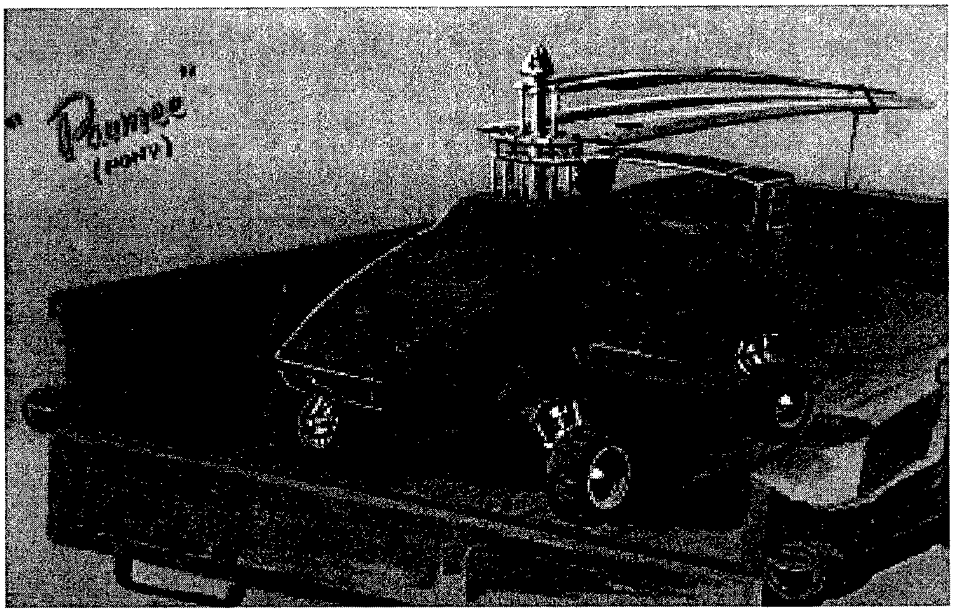


Figure 1 Baseline Configuration "The Rolling Feather"

4.0 THE ALTERNATIVE CONCEPTS

Figure 2 shows the alternative concepts that each team synthesized following the baseline design. This section of the paper will give a summary of the basic air and ground propulsion aspects of each design and the overall rationale of each team's selection of a preferred concept.

4.1 Team 1 Alternative Concepts

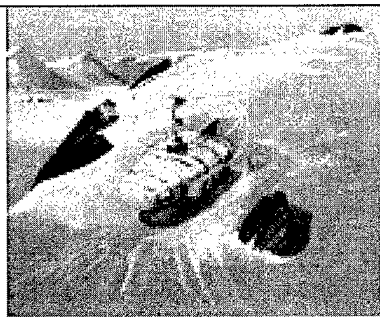
Concept 1A, The Seagull, is an unmanned coaxial rotorcraft designed to take off vertically. Conventional batteries that run electric motors attached to wheels that run tracks power the ground mission. The weight of the craft is 1500lbs. The Seagull uses tracks to move on the ground. The fuselage is made of lightweight composite material. Reinforcement panels are placed around sensitive areas in the vehicle; materials such as Kevlar are used.

Concept 1B, The Fighting Duct, makes use of a ducted fan concept coupled with turboprops for flight and tracks for ground operations. A single co-axial, ducted fan is positioned in the center of the "flying wing" and is used solely for hover and climb. Three individually powered tracks will be used for ground operations. Avionics sensors are located in the nose of the vehicle and will provide for semi-autonomous flight and ground operations.

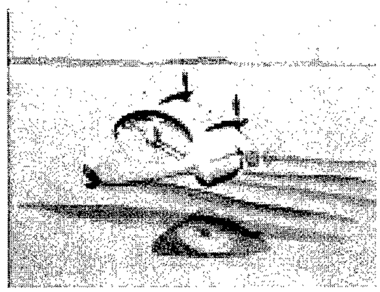
Concept 1C, The Choctaw, draws all of its operational power from Proton Exchange Membrane (PEM) fuel cells.[15] The rotor disc is 15 ft in diameter, with two blades of aspect ratio 18 for each rotor. Four individual 2-hp electric motors provide power to the four wheels for extremely quiet ground maneuvers. Avionics and its sensors guide the flight and navigation of the vehicle through nap of the earth flight paths and remote-controlled video operation will be available where communication conditions permit.

Figure 2 IPT 2002 Alternative Concepts Phase 2

Team 1



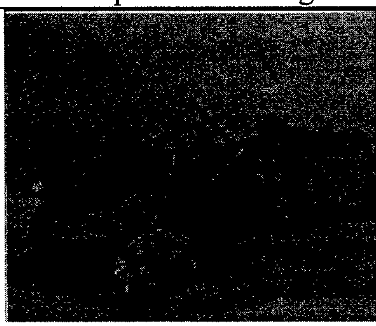
Concept 1A-The Seagull



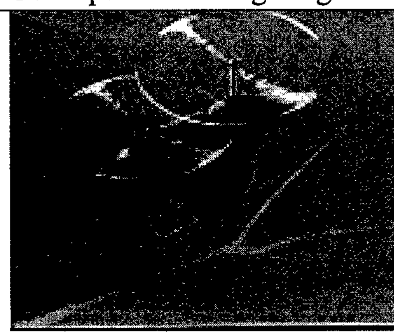
Concept 1B-The Fighting Duct

Concept 1C-The Choctaw

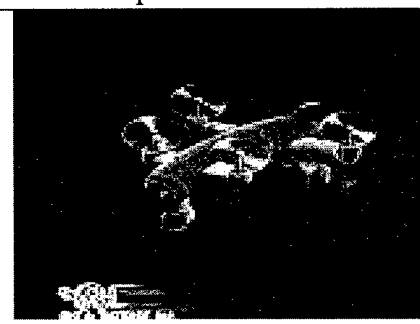
Team 2



Concept 2A-The Mole

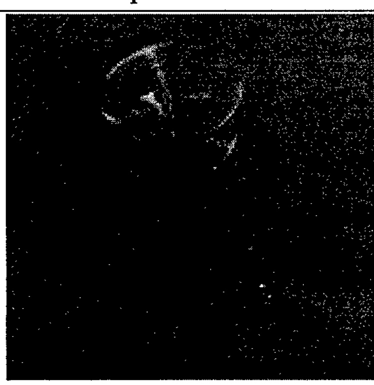


Concept 2B-The Hummingbird

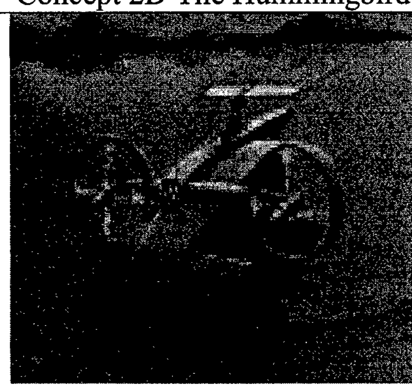


Concept 2C-La Fouine

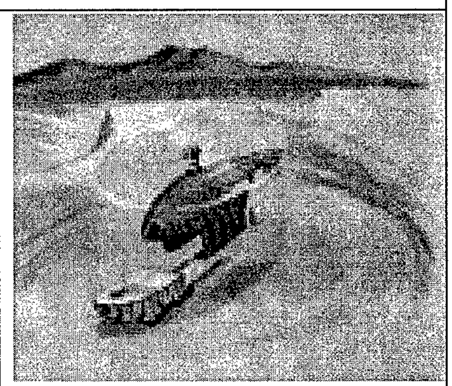
Team 3



Concept 3A-The Weasel



Concept 3B-The Womprat



Concept 3C-The Chicken Hawk

In the end, J5 Engineering selected the Choctaw parallel hybrid approach as the final concept. The Choctaw exceeded the baseline concept in ground speed [due to the use of wheels rather than tracks], endurance and range due the use of efficient fuel cells that should extend the range significantly [as the fuels are much lighter], weight [given that development can probably result in a lighter vehicle], and acoustic signature.

4.2 Team 2 Alternative Concepts

Concept 2A, The Mole, is a two-piece design. The design utilizes intermeshing rotors powered by a 230 hp SMA SR/305 diesel engine.[16] The rotor disk radius is estimated at six ft. The helicopter carries an independently powered ground vehicle. The total system weight is estimated at 1472 lbs including a 35% allowance for design contingency. The ground vehicle is powered by two electric motors. With this two-piece design enhanced ground maneuvers are possible, overall ground mission endurance is increased, and for very dangerous missions, the aircraft can return to the ground station while the ground vehicle remains behind.

Concept 2B, The Hummingbird, utilizes a rotopter rotor design powered by a 180 hp Noelle turbine engine.[17] In the rotopter, the engine drives the crank causing the blades to go up and down. With careful selection of the airfoil angle, the blades will rotate as a result. With this system there is no moment transmitted to the rotopter blades, so there is no torque reaction. The Hummingbird design has a tandem rotor system with a disk radius of five ft. The energy source used for ground transport includes both batteries and fuel cells.

Concept 2C, La Fouine, utilizes a tilt rotor system powered by a Saphir 180 hp Turbine Engine.[16] The rotors can tilt forward during flight and become like propellers on an airplane. This allows a tilt rotor to achieve airplane type speeds and remain stable. The rotor disk on the La Fouine design has a radius of four ft. The ground segment is powered by two electric motors requiring 36 Volts and 62 Amps. The total system weight is estimated at 1487 lbs including a 20% allowance for unidentified components.

The Mole was chosen as the best concept to refine in phase three. The Mole was superior to the baseline with regards to air speed, vertical climb, horsepower required for flight profile, and overall endurance. A two-piece design offers more flexibility in mission profile. The Mole also allows enhanced ground operations because clearance of the rotors is not an issue. The ground vehicle, being much lighter than the overall system, will have enhanced ground endurance as well as increased maneuverability.

4.3 Team 3 Alternative Concepts

Concept 3A, The Weasel, is similar to the Baseline. It is comprised of a coaxial rotor system and a three-wheeled ground configuration. This design utilizes a more complex transmission system as compared to a standard helicopter. This rotor system minimizes overall size of the vehicle due to the omission of a tail for control.

Concept 3B, The Womprat, is powered during the air portion of the mission by two ducted fans as opposed to a traditional rotor disk. An Allison Model T63-A-700 Gas Turbine engine drives the fans.[18] The ground configuration consists of a set of wheels that will not be powered. As the ducted fans tilt, they will rotate into a position that will permit them to provide the force needed to move the vehicle on the ground.

Concept 3C, The Chicken Hawk, is a fully autonomous system that combines a separate unmanned ground unit into an unmanned helicopter. It uses a single rotor with a counter-torque tail rotor. The ground unit is a four-wheeled electrically driven vehicle. The aerial unit will have the ability to return home with or without the ground unit.

Though more complicated, the Chicken Hawk concept has the most potential for development. Since the gross weight of the vehicle was lowest for this concept, the power requirements are much less as is the overall size. Due to the Chicken Hawk's ability of meeting or exceeding the customer requirements and it's adaptability to various missions and payloads, the Chicken Hawk's potential to be an extremely valuable to the future ground forces.

5.0 THE FINAL PROPOSALS

5.1 Team 1 Solution - The Choctaw

The Choctaw UHV is a coaxial rotorcraft driven by four independently powered, electrically driven wheels that are fixed below the main part of the pistachio-shaped fuselage. The final

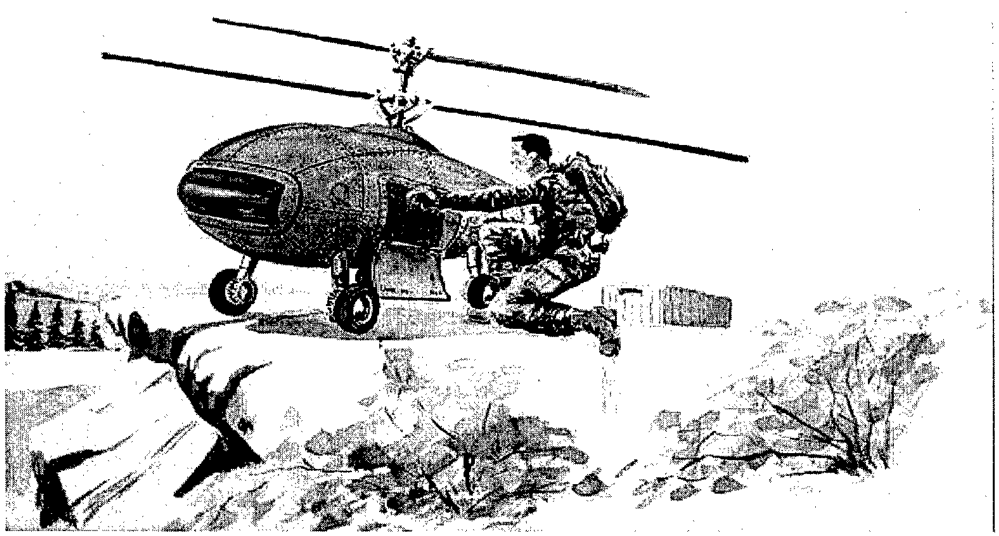


Figure 3 Team 1 Solution - The Choctaw

concept includes spring-loaded coaxial blades with servo flaps, a hybrid propulsion system consisting of fuel cells, electric motor, and ultracapacitors, four motorized wheels, and payload situated near the center of the vehicle.

The basic design of the final vehicle is a co-axial rotorcraft much like the one presented in the baseline design. In this design, two main rotors are used on the same shaft. One rotor will turn clockwise, while the other will rotate counter-clockwise. The motion of one-rotor disk counters the torque produced on the vehicle by the other rotor disk. This eliminates the need for a separate, torque-countering device such as a tail rotor and thus conserves space. The main goal aerodynamically was to retain a low weight estimate for the vehicle and increase the overall aerodynamic performance of the vehicle. To accomplish this in the design of the rotor blades, composite materials were used, which are high in strength and low in weight. By hollowing out the inside of the blades and placing spars at even spaces along the span, a minimal weight can be obtained without compromising the structural stability. A rotor diameter of 7.5 ft was determined and an adequate amount of thrust could be generated from the rotor disk without demanding too large of a power output from the propulsion system.

The rotor tip speed is assumed constant at 650 ft/sec. A tip speed in this range ensures that the blades will not encounter supersonic flow throughout the flight profile. Thus, compressibility, particularly on the blade tips, can be ignored.

Two concepts were considered at length for use in the Choctaw. One system used two internal combustion engines (ICE) to provide power to the rotors as well as to turn an alternator in order to provide electricity for ground power and avionics. The other system used an ICE for air propulsion and a fuel cell system for ground and avionics power. The air engine chosen is manufactured by a German firm named Zoche Company. This engine is a two-stroke engine, radially arranged, with four pistons. The air transmission system is sized in order to support the UHV's maximum lift forces during the climbing, because it is the worst load case for this system. This system has to support the maximum constraints due to the maximum engine torque. The other parts like axis or bearings have to support the UHV loads with a minimum deformation in order to run correctly. To make power available when needed by the application, ultracapacitor charges itself power from the fuel cell. This power is then discharged from the ultracapacitor at rates demanded by the application. The ultracapacitor can be repeatedly charged and discharged at rates optimized for the application. It allows the entire system to be tailored to optimally meet both power and energy requirements. From a mission point of view, fuel cell allows flexibility: The Choctaw can gain room for the payload, or fuel in order to increase the duration of the ground phase or the performances of the UHV.

The ground robotics system features four 9-inch wheels that are electrically driven and have a spring suspension. Skid steering is simply accomplished by fixing the orientation of the wheels and alternating the rotation characteristics of each wheel independently to rotate the vehicle. To execute a right-hand turn, this design depends on the avionics system to command the tires on the left side of the vehicle to turn in the forward direction while the tires on the right side of the vehicle turn in the backward direction, all at the same time, to spin the entire vehicle so that it faces right. A three-hp electric motor was selected for each wheel such that the diameter of the electric motor would be small enough that the electric motor might fit into the hub of the wheel with enough clearance for the hub of the wheel to spin freely around the edges of the electric motor. The wheels selected featured a hub whose depth into one side permitted three inches of penetration at a hub clearance diameter of 7.5 inches. The electric motor featured a maximum diameter of seven inches. The 0.25-inch clearance will be sufficient for this rigid design. The drive shaft of the electric motor will be bolted to the wheel hub. The ends of the shaft will fit into bearings allowing the drive shaft and wheel to spin together, freely. All other components of the ground robotics system are fixed. The electric motor will be powered via wires that run along the shaft that the motor housing is mounted to. To address high-impact landings from flight, stiff springs bearing loads of up to 3000 lb will be installed above the wheel faring to allow up to six inches of spring compression in the event of a hard landing.

The frame is constructed of Titanium IMI 834 having a density of 0.164 lb/in^3 and modulus of elasticity of 17400 ksi. The fatigue and ultimate tensile strength are 76.9 ksi and 152 ksi, respectively. The core material is Nomex honeycomb with density of 0.000686 lb/in^3 and shear modulus of 4.06 ksi combined with epoxy resin. The skin of the Choctaw is constructed using Aramid Fiber/Epoxy combination. Due to the operation environment, impact resistance was considered. Aramid fibers are used extensively in ballistic applications having high tensile strength of 450 ksi, elastic modulus of 19000 ksi and low density of .052 lb/in^3 giving very high specific strength. The rotor blades are constructed using carbon fiber/epoxy advanced composite having a density of .0614 lb/in^3 and ultimate tensile strength of 129 ksi. It is constructed using prepreg molding. A portable repair system also known as "Hot Bonder" is especially useful for field repairs in situations where it is hard or impossible to remove damaged part. The Choctaw's fuselage resembles that of a pistachio nut. It is round in the longitudinal direction and the front and back of the vehicle tapers toward the center, forming a streamlined shape. The Choctaw also features removable panels that are inside the payload area, this allows easy access to change out the fuel cell or the ultracapacitors. Table 2 shows a weight breakdown for The Choctaw.

Table 2 Weight Breakdown

System	Weight (lb)
Air Drive System	357
Ground Drive System	171
Avionics and Sensors	124
Structural Weight	150
20% Weight Contingency	160
Mission-Dependent Weights	220
Support and Handling Equipment	245
Total Shipping Weight	1312

One of the main components that allow semi-autonomous to autonomous flight is the Differential Global Positioning System (DGPS). The central processing units (CPU's) needed for flight control including the full authority digital engine control (FADEC), video and synthetic aperture radar (SAR) processing and secure communications are all in one location. The communications of the UHV will be by satellite communications [SATCOM] links that use secure wireless Ethernet Wavelan technology for remote and BLOS controls. The Fluorescent Aerodynamic Particle Sizer (FLAPS) system is going to be used to gather information on Chemical and Biological threats. The target sight system is the FLIR/Camera/Radar/IFF sensor. This sensor will provide visibility, object detection, radar images, and full motion video. The

Wescam Suite and the Vaisala DRD11A Rain Detector sensor will be capable of detecting weather activities.

In determining each mission profile, the analysis assumed the vehicle and payload weight is 1100 pounds. The maximum power of the engine is 150 horsepower. Table 3 illustrates the engine function through the segments identifying horsepower requirements and power usage in percent relative to maximum available horsepower.

Table 3 Engine Function Ratings

Function	Required Horsepower	Usage Percent (%)
Climbing	125 hp	83.33
Cruise	70 hp	46.76
Descending	65 hp	43.00
Hovering	110 hp	73.33
Idle	10.5hp@750rpm	7.00

In an effort to provide a unique design that will provide benefit to the customer, J5 Engineering personnel developed an alternative electrical power generation system that should perform similarly well while providing many added benefits. A fuel cell will be used to replace the alternator in terms of providing average power. The Choctaw UHV will have a tank of hydrogen on board to be mixed with atmospheric oxygen to produce electrical power on an average need basis.

5.2 Team 2 Solution - The Mole

The Mole is a two-piece design that utilizes a synchropter rotor system as shown in Figure 4. The helicopter carries an independently powered ground vehicle. The helicopter is fully capable of surveillance flights without the added weight of the ground vehicle. The total weight with the support and handling equipment is 1487 lbs. With this two-piece design, enhanced ground maneuvers are possible, and overall ground mission endurance is increased. For dangerous missions, the aircraft can return to the ground vehicle while the ground vehicle remains behind. This increases the overall survivability of the system. The disadvantages of this system include: 1) some duplication of sensors will be required; 2) the system will require a minimum of two brains; and 3) a transmission is required for the synchropter rotors adding additional weight to the system.

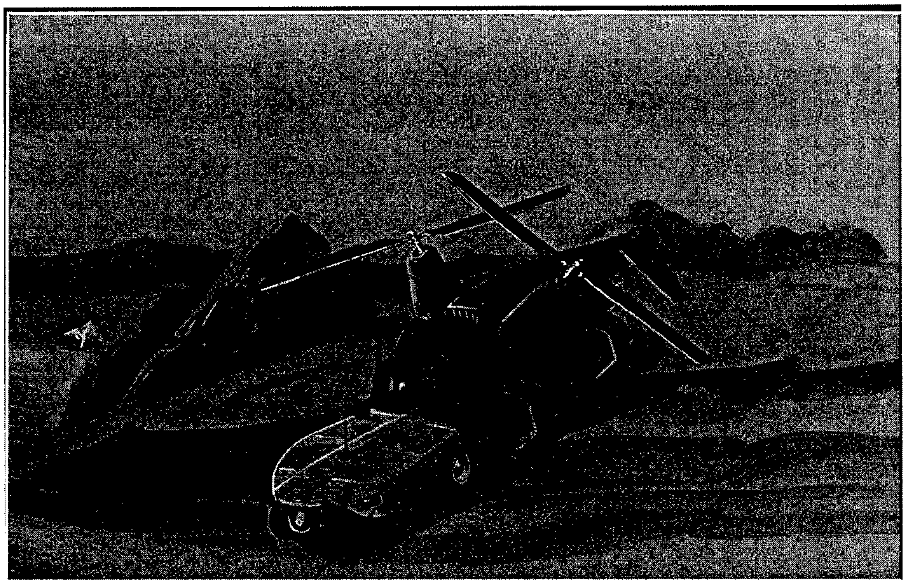


Figure 4 Team 2 Solution - The Mole

The Mole uses a synchropter rotor system to provide the necessary thrust to propel the system. The two separate rotors rotate in opposite directions to each other. This removes the need for a tail rotor reducing the amount of power required for flight. The results of the power analysis at a helicopter weight of 1400 lbs, a rate of climb of 500 fpm, and a rotor radius of 7.2 ft are: Induced Power of 136 hp, Parasite Power of 0.70 hp, Total Power Required of 137 hp, Rotor Tip Velocity of 417 ft/sec, and Rotor Frequency of 553 rpm. Carbon fibers were preferred for the blade material because of their high strengths and low weights. RTP Company RTP 2587 Polycarbonate/ABS Alloy (PC/ABS) Carbon Fiber 40% was selected.

Servo flaps were also used on the rotors. Servo flaps are small airfoils located on the trailing edge of the helicopter blades. Push-pull control rods control the flaps. The servo flap is used to adjust the pitch of the blades. The flaps eliminate the need for a complex and heavy hydraulic control system. The flaps also reduce the amount of vibrations that occur in the blades because of the changing lift.

The engine chosen by Hybrids R US was the Zoche engine. This is a German engine, which presents the best characteristics to meet the CDD requirements. Specifications for the Zoche Engine are: 150 hp at 2,500 rpm, Height of 21.8 in., Width of 21.8 in., Diameter of 25.5 in., Length of 28.5 in., Weight of 185 lbs, .365 lb/hp hr Max Power BSFC, .346 lb/hp hr Cruise (75%) Consumption, 5.57 gal/hr Cruise (75%) Consumption, and Uses Diesel Fuel #2, Jet Fuel JP 4, JP 5, JP 8, Jet A.

A centrifugal clutch was chosen for The Mole. It is dense, simple and sturdy. It does not require any electrical alimentation or hydraulic commands. A helical gearing system was chosen for The Mole. It will have only three engaged gearings between the clutch and a rotor shaft. It will be sized to obtain the needed reduction ratio of three. The estimated dimensions of the main gearbox are: Length of 10.6 in., Width of 5.9 in., and a Height of 5.9 in. For The Mole, a freewheel is required to prevent the rotational motion of the rotor from a brutal stop in the case of an engine or clutch break. It will be placed after the main gear box, between the two rotor shafts which will increase the reliability of the propulsion system.

The ground system for The Mole utilizes a three-wheel, V-shaped system, powered by two electric motors, one on each back wheel. Using a technology known as skid steering, by holding one wheel stationary and moving the other wheel a turning motion can be generated.

After comparing electrical motors, two were chosen with the following specifications:

- Max Rotation Speed: 3300 rpm
- Max Torque: 116.8 lb_f*in
- Motor Weight: 8.5 N
- Total Power Required: 2.95 hp

The weight of the electric motors combined is approximately 76 lb. The dimensions for the wheels are eight inches in diameter for the two rear wheels, and ten inches in diameter for the front wheel. The wheels are made of aluminum and have an approximate weight of 35 lb. Using the above components, the total weight of the ground robotics system is 111 lb. A total weight of approximately 135 lb is realized, for additional elements and attachment hardware. Table 4 is a weight breakdown for The Mole.

Table 4 Weight Breakdown

System	**Weight (lb)**
Air Drive System	415
Ground Drive System	251
Avionics and Sensors	246
Structural Weight	95
20% Weight Contingency	201
Mission-Dependent Weights	179
Support and Handling Equipment	100
Total Shipping Weight	1487

Table 5 contains the primary material used in The Mole.

Table 5 Materials Used

Component	Material
Frame	Titanium
Skin	Beryllium-Alluminum Alloy
Tire Material	Vinyl
Wheels	PTS Grade Fiber Reinforced Plastic
Rotors	Carbon Fiber AS4C

The payload will be located in the center of gravity on the ground unit. The payload will be accessible through a door on the side of the unit. It will have a latch and pulley system that will unload and load the payload. It will also have a biochemical detection system that can relay information back to the air unit for storage or immediate relaying back to the base. It will also have the capabilities to send images the same way the biochemical system does.

The motor is located directly under the rotors to help in the center of gravity and also the simplicity of the gearing system. The fuel tank is located directly in the center of gravity to insure that as the vehicle consumes fuel it will not upset the balance of the entire aircraft. The camera will be located on the tip of the nose for better vision. The avionics are located near the back to offset the biochemical system that is located at the front of the aircraft. The ground unit will be latched in under the aircraft until deployment and will enter and exit from the rear of the air unit. The air unit will also have sling latches located on the top of the aircraft, at the four corners.

The Mole's flight control is provided by an integrated avionics subsystem that incorporates most basic navigational functions and provides control outputs. The Mole is capable of navigating a pre-programmed set of waypoints using GPS. The aerial vehicle houses the primary long-range communication components, which provide both LOS radio and BLOS satellite relay capability. Low-power, short-range communications capability is included so that the aerial vehicle may act as the control and relay center for the ground vehicle during its mission. The aerial vehicle also incorporates a package for the detection and identification of airborne biological and chemical agents.

The Mole contains three main computers: the MIAG (Modular Integrated Avionics Group), the RVM (Reconfigurable Vision Machine) and the Flight Control computer. The MIAG is a complete management system specifically for use in UAV's that incorporates a DGPS-capable Global Positioning receiver, a fiber optic inertial measurement unit, local air data pressure transducers, and an IFF transponder. The MIAG is capable of exchanging data with the flight computer as well as providing outputs for engine control and steering. Two MicroSTAR FLIR cameras are capable of capturing data using dual imaging sensors – high resolution infrared and bore sighted CCD-TV with low-light capability. Their lightweight and compact design translates into saved fuel, minimized drag, increased mission duration, and improved weight and balance calculations. (MicroSTAR, March 2002) The Mole is able to follow terrain either by matching its current GPS-provided location with terrain data from a loadable map, or by using its twin FLIR/CCD imagers with the RVM vision-based terrain following system. The RVM has the dedicated, real-time performance and data transfer bandwidth needed to guarantee vision results at the required rate. The Flight Computer is the control center for all communications and sensor processing. It accepts inputs from the Aerial and Ground Vehicles, the MIAG, the RVM, and the ground station. It processes all inputs and sends pertinent information to the other computers allowing them to adjust for obstacles and unplanned problems. It also transmits information to the ground station through a direct link and via satellite uplink. The Mole also utilizes a miniature radar altimeter that provides a constant altitude-above-ground measurement up to 700 m (approximately 2300 ft) as an augmentation and backup to the vision-based system.

In addition to ground tracking and terrain following, the RVM runs algorithms for object detection, object tracking, and localization. The dual cameras are mounted on swivel turrets and may be aimed from the remote ground station when they are not being used for automated tracking. The Mole communicates with its ground station using secure CDL (Common Data Link) transmitters. Currently, The Mole is designed to support CDL Class I for LOS communication and CDL Class IV and V for satellite relay BLOS.

The Mole's ground vehicle incorporates its own independent sensors and processors, although they are of reduced complexity compared to the aerial vehicle. The ground vehicle incorporates a GPS receiver so that it may follow a pre-programmed route and re-trace that route to return to the aerial vehicle if necessary. The ground vehicle's key capabilities include autonomous navigation, chemical and biological agent detection, and video relay. The ground vehicle uses low-power transmitters to communicate with the aerial vehicle and report its location and status. The aerial vehicle's main computers may be configured to relay the ground vehicle's information to a base station in real time or simply to record specific information for later download at the base station operator's request. A small chemical and biological detection subsystem known as Lab-On-A-Chip is being developed at Sandia National Laboratories. The ground vehicle's "eye" is a single, small camera in the nose of the vehicle. This camera is to be used for image capture and relay only. It may include a visible or IR illuminator for use at night or in low light environments. For navigation, the ground vehicle relies on GPS. The GPS system is augmented by infrared proximity sensors mounted on the front corners of the vehicle to provide for basic obstacle avoidance. The ground vehicle incorporates a general-purpose central processing unit to accept GPS data and control signals from the aerial vehicle, process sensor data, control vehicle speed and steering, and relay information to the aerial vehicle.

The simulations for The Mole assume that the Total Takeoff Weight is 1400 lbs; the VROC is 500 fpm; 10 US gallons of Diesel Fuel Grade 2; flight speed is at the estimated most economical; and the ground vehicle weighs 200 lbs. The Aerodynamics team supplied the required power values, which indicates that the most economic flight speed is approximately 72 km/hr. This speed was used in all subsequent simulations. The simulations indicate that six gallons of fuel would be adequate for the specified mission profile. NOE flight conditions were taken into consideration by doubling the forward flight distance. A 10% fuel reserve was added to the required fuel and the NOE conditions. The actual fuel tank was sized for a ten-gallon fuel capacity. The actual fuel reserve with this design is estimated at 67%. Additional simulations indicate that the point-to-point flight endurance with the ground vehicle is 340 km, 4.83 hr, and 9.9 gal. The point-to-point flight endurance without the ground vehicle is 425 km, 6.01 hr, and 9.9 gal.

The ground mission is powered by four 12-Volt batteries. The batteries supply the electric motors and the sensors that are utilized during the ground mission segment. Simulations show that the duration of the batteries at the 62 Amp load is approximately 40 minutes. The CDD requires a 10-minute duration for the batteries. It is anticipated that most of the sensors will run continuously during the two-hour ground mission segment. The amperage load on the battery is approximately 12-amp. The endurance of the battery that powers the sensors is approximately 4.5 hours.

The Mole meets and exceeds all requirements set forth by the customer in the concept description document. It utilizes technology that is available today and can be deployed by the year 2012.

5.3 Team 3 Solution - The Chicken Hawk

The Chicken Hawk, as shown in Figure 5, is a UHV capable of meeting the needs of the US Army. This system is a unique vehicle in both the way it meets system requirements and in its robustness as a combat tool. The key to this system is that it is comprised of two separate vehicles. The engine and transmission provide both mechanical power to drive the vehicle in the air and electric power to recharge the batteries on the ground vehicle as well as run the internal electronics. Each vehicle contains an onboard computer to manage data flow and operate the vehicle. The primary sensor package lies in the ground vehicle. This package provides the sensory data needed during flight and the information is relayed to the air vehicle. It also provides similar data during the ground portion of the mission. Having only one set of sensors reduces system complexity and weight. For communication each vehicle carries a satellite radio, which allows independent communication to the base station and provides some redundancy.

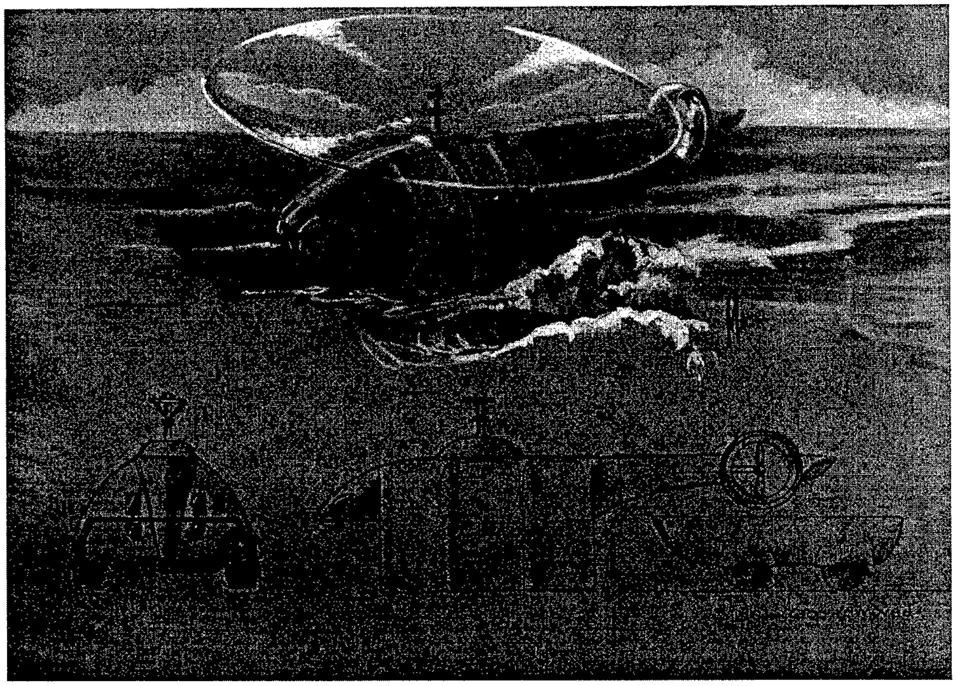


Figure 5 Team 3 Solution - The Chicken Hawk

The main rotor span of the Chicken Hawk was limited to 16 feet to make the vehicle more transportable. This restriction caused the main rotor to be a lower aspect ratio, which is 12; therefore, the main rotor system is slightly less efficient. The minimum power required for cruise is at approximately 55 mph. This is also true for climbing at 500 fpm. A greater amount of power is required to drive the tail rotor at hover. This is because the tail rotor is the only counter torque device in this flight condition. When the aircraft is in forward flight, the tail area provides some counter torque.

The engine chosen for this system is the ZOCHE ZO 01A, which is a four cylinder two stroke diesel engine. This engine is nearly quiet and offers the best power-loading ratio for the requirements. The transmission system is composed of six gearwheels and four shafts to drive the power from the engine to the main and tail rotors. There are also two clutches that allow the engine to work without any rotation of the rotors. The main rotor transmission is made of an engine shaft linked to a clutch and then to the first gearwheel. This gearwheel is in connection with a second gearwheel, which drives a conic gearwheel via an intermediate shaft. This conic gearwheel drives the main rotor shaft via a second conic gearwheel. The tail rotor transmission is made of an engine shaft linked to a clutch and then to the first gearwheel. This gearwheel is in connection with a second gearwheel; the same one that drives the main rotor also drives the tail rotor.

The Chicken Hawk consists of a four-wheel configuration for the stability of the vehicle. Only the four wheels are powered by two electric motors (directly connected to the wheels) to allow the vehicle to be as silent as possible while the ground portion is performing the mission. The two motors have to provide an output power of 0.72 hp each during the two hours of the mission.

33 amps need to be provided to those two motors so the system of batteries has to have a capacity of 132 Amp hours. The motor has a 1000 to 4000 rpm shaft output. Two systems have to be put between the batteries and the motors, a variator, which controls the voltage input in the motors in order to range the rotation speed at the shaft output. Also, a controller, to modulate the different voltage at the input of the two motors when the vehicle has to turn, in order to accomplish the differential steering. The wheels chosen are eight inches in diameter and four inches width. Each one weighs nine lbs. In one second, the vehicle has to run at 5.47 ft/s so the wheels have to turn at 0.2 rpm.

In the Chicken Hawk's concept design, there are two separate frames; one for the aerial system and the other for the ground system. Both systems are designed with the same technique. The chassis are composed of 0.5 in^2 cross-section rods of specific materials interwoven together forming light strong frames with enough surface area to allow component mounting, but not so much area as to drive the weight of the structure too high.

Two materials make up the composition of these rods. The first is a 35% Glass Reinforced Styrene Acrylonitrile polymer. This material has a low density to strength ratio but low flexibility. It is an ideal component for dimensionally stable structures. This works best in the main structure of the aerial and ground systems where a larger surface area is needed for part mounting. The other material is Aluminum 6069-T6, which has a low density to strength ratio and a good elastic flexibility. This material is ideal for the support structures of the skids and the tail where aerodynamic forces might cause some structure flexing. This Aluminum would be too heavy though for the larger surface areas. The chassis weight totals at about 52 lbs.

The weight of the vehicle is the most important factor in dynamic calculations. Prediction of a vehicle's real final weight has always been a very laborious and inaccurate process. A 40% inaccuracy factor has become a reliable standard over the years in calculating weight. The total weight came to be approximately 1249 lbs. Table 6 shows a complete weight breakdown of The Chicken Hawk.

Table 6 Weight Breakdown

System	Weight (lb)
Air Drive System	371
Ground Drive System	245
Avionics and Sensors	163
Structural Weight	69
40% Weight Contingency	307
Mission-Dependent Weights	214
Support and Handling Equipment	152
Total Shipping Weight	1402

The electronics necessary are divided into three categories: the electronics for the ground portion, the avionics for the helicopter portion, and the ground station. During flight, the ground portion of the system houses the optical package and relays the information to the air portion via short-range radio for flight control and for further relay via satellite radio to the ground station. Following the mission profile, the two portions of the vehicle begin the mission joined. Once the vehicle has reached its destination it will begin searching for an area large enough for the craft to land using the main optical system and land as close to the initial coordinates as possible. The ground station can designate the pattern used for searching as either spiraling outwards in all directions or with limitations so that the craft will not enter an area enemy troops may occupy. Once the system has located a possible landing site it will query the ground station for landing confirmation at the new coordinates. Once the system has landed it will disengage its rotors and the ground portion will be released from its docking restraints. The ground portion will then back out of its carrier and proceed with the ground portion of the mission. During this time it will continue to relay the information it collects from its optical array and chemical detection system to the ground station. It will also track its path with its GPS so that it has at least one reliable return path to the air portion. Once the ground mission is complete the ground portion will return to the air portion and reenter the docking area using the main optical device for guidance. After the ground portion has been locked into position the UHV will takeoff and return to base.

The most important of the avionics package is the Central Processing Unit (CPU), which controls the flight and all other functions of the aircraft. The Modular Integrated Avionics Group/Navigation Sensor Unit (MIAG) utilizes a Global Positioning System (GPS) receiver for preprogrammed aircraft navigation as well as general aircraft position data. The air and ground portion has two independent radio systems. The first is a simple short-range radio used for communication with the ground portion. The second is a satellite radio for beyond line of sight (BLOS) communication with the ground station. For positioning data the ground portion uses a simple GPS to keep track of its location. The main optical element within is a forward-looking infrared (FLIR). It operates in the 5-8 micrometer range and is coupled with an infrared pulsing light emitting diode (LED). The system operates similar to a radar system during flight.

Simulation takes a complex situation and simplifies it into a more convenient form. The purpose of simulation is to explore the various outputs in order to understand the system. In this case the complex situation is the basic mission profile given by the customer. It has been simplified into the excel spreadsheet shown in Table 7.

Various mission profiles and fuel requirements have been explored in order to understand exactly how this system will perform.

Table 7 Power Requirements for the Flight Phases

Flight Phase	**HORSEPOWER REQUIREMENTS**	**% Engine Power**
Hover/Land	116	77
Climb (VROC 500 fpm)	146	97
Efficient Cruise (46 mph)	82	55
Cruise Speed (30 km/hr)	91	61
Warm up/Idle	91	61

In addition the fuel requirements for alternative missions were calculated. All of this information is shown in Table 8. Based on the calculated fuel requirements the UHV design uses a 20-gallon fuel tank. However it will depend on the intended mission how much fuel is used. It is possible to increase the payload amount by reducing the amount of fuel used. Theoretically, if only the Baseline Mission is performed it is possible to increase the payload amount by 74 lbs, creating a total payload mass of 134 lbs.

Table 8 Fuel Requirements

Mission Profile	Fuel Requirements Mass (lbs)	Fuel Requirements Volume (gallons)
Baseline	53.78	7.38
Idle during Ground	64.34	8.9
Hover during Ground	146.44	20.45
Cruise during Ground	102.01	14.17
Maximum Design	141.53	20

The only technical decision that was studied was the use of a coaxial rotor system instead of the single rotor with a counter torque tail. An extensive trade off analysis was performed, both technically and programmatically. Though a coaxial system requires less power through most flight regimes, the ultimate decision was to stay with the single rotor system. This type of system has been proven in combat for many years. There are several commercial transmissions that could be purchased today that would need very little adjusting to meet our requirements. The transmission weight would be approximately the same for both systems. However, when one looks at all the aspects in a system wide view, the single rotor has the cheapest, most reliable, and quick development timeline of the two options.

5.4 Verification of Concepts

After the competition, a team of professors briefly reviewed each to verify the correctness of the calculations. Appendix F contains memos that provide detailed comments. The following subsections summarize the comments of the concept verifications.

Team 1

The basic concept of team one appeared to be a feasible configuration. A significant error in the hover power calculation was noted. The mission simulation calculations for the air portion appear valid. No explicit calculations are shown for the ground segment. The concept used spring-constrained blades in a coaxial configuration without supporting structural analysis to verify its feasibility. The propulsion concept matches the calculated power, fuel, and air mission profile requirements. There was very little information in the report to document or explain the avionics and ground mission calculations. If this concept were investigated further, the power requirements and resulting battery weights would be a key consideration in verifying the vehicle gross weight as presented.

Team 2

The configuration of this concept is feasible as reported. The power required for the rotors may be conservative which leaves some room for growth in the vehicle weight or additional payload. The mission simulation had excellent assumptions and documentation for the air portion. There is no structural verification presented of the blade deflection or airframe. The propulsion concept matches the calculated power, fuel, and air mission profile requirements. The ground robotics calculations appear to be incorrect. They did not allow for the efficiency of the electric motors. This would have a significant impact on the weight of the ground vehicle. If this concept were investigated further, further investigations on the ground mission, power requirements, and weights would be an important consideration as it will increase the weight of the vehicle.

Team 3

The concept is feasible as presented in the report. The rotor calculations appear correct. The air portion of the mission simulations appear to e valid. No detail is presented for the ground mission simulation. The report does present a detailed weight and balance statement on the components. The propulsion concept matches the calculated power, fuel, and air mission profile requirements. The efficiency calculation on the ground power appears to be incorrect. The electric motors and batteries need to be resized. The wheel revolutions are not correct as presented. Further investigations of this concept should begin with ground mission simulations and a resizing of the ground propulsion system.

Summary:

In general, the biggest question on all the concepts in the ground mission performance, power requirements, and the resulting weight. The assessments of the concepts indicate that the power and weight of the ground systems may be underestimated in all the configurations.

6.0 THE SELECTED CONCEPT

6.1 Review Team Selection

Table 10 summarizes the key technical characteristics presented by each of the teams. It also shows the key enabling technologies that will need investment to realize the implementation of the concept. Table 11 summarizes the each teams concepts technical information.

The Review Team evaluated and ranked the three concepts. They based the evaluation on a written document from each team, a team oral presentation, and an oral question and answer session with each team. The results presented in Table 9 represents the averages in each category for the seven review team members. The Review Team selected Team 3's concept as the winner of the contest.

Table 9 Review Team Scoring Results

Category	%	Team 1	Team 2	Team 3
Technical Content	35	30	29	32
Organization/ Presentation	20	18	17	18
Originality	20	19	17	18
Application/ Feasibility	25	19	18	20
Total		85	81	88

To also gain some perspective on the distribution of opinion, if each reviewer's individual selection were counted as one vote, the results are Team 1: one vote; Team 2: one vote; and Team 3: five votes.

The Review Team was very complimentary of all teams' professionalism, quality of the written reports, and oral presentation skills. They commented on the students poise in answering questions and the depth of understanding that they had developed about the overall conceptual design process in such a short time. In general, they felt greater fidelity in structural analysis could have been performed by all the teams. There was also concern over the interchanging of English/metric units among the various disciplines and in the CDD. The following paragraphs give the instructor's interpretation of Review Team comments about each proposal.

The overall strength of Team 1's proposal was their originality and innovations in the areas of fuel cells and servo flaps. With innovations, however, come feasibility issues for a 10-year deployment timeline. There were some practical concerns about the logistics and handling of hydrogen to support the fuel cells, and development time issues with the coaxial rotor with servo flap technology. For the remote operations they foresaw some limitations with the compressed air ignition concept and manual unloading of payload. The presentation was exceptional, showing confidence and consistency.

Team 2 showed a balanced effort in all categories. The main innovation in this concept was interpreting the specification to provide a two-piece design. This allowed for deploying and retrieving the payload without crew as well as greater mission scope and flexibility. Concerns were expressed in the areas of ground power design, payload attach and release mechanisms, and BLOS control of the vehicle. The Review Team praised the team's extensive use of simulation to address multiple topics.

The overall strength of the Team 3 proposal was their technical content. The material was exceptionally well presented and organized. Assumptions and relevance to CDD requirements were thoroughly addressed. Advantages to the customer clearly defined. The reviewers liked the innovative two-stage system with a simple attach/release mechanism. The team delivered good definitions of fuel trades for various missions, a good communications architecture, and a balanced treatment of all requirements. Team 3 was also judged strong in the

Application/Feasibility arena. In particular, reviewers liked the use of available technology to reduce R&D cost, the inclusion of a 40% design weight margin, and a low risk single rotor.

Table 10 Final Concept Evaluation-Baseline Mission Profile

		Team 1	**Team 2**	**Team 3**
CDD Requirement	**Requirement**	**Choctaw**	**The Mole**	**Chicken Hawk**
Payload	60 lbs	60 lbs	60 lbs	120 lbs
Endurance	4 hours	4 hours	4.8 hours	3.71 hours
Flight Profile	Hover-Full	Hover-Full	Hover-Full	Hover-Full
Vertical Climb	200 fpm	200 fpm	500 fpm	500 fpm
Operational Altitude	0–250 ft AGL	0–250 ft AGL	0-250 ft AGL	0–500 ft AGL
Airspeed	30 km/hr	30 km/hr	72 km/hr	259 km/hr
Ground Speed	6 km/hr	6 km/hr	6 km/hr	6 km/hr
Operation	Semi-autonomous	Semi-autonomous	Semi-autonomous	Fully autonomous
Communication	BLOS	BLOS	CDL	BLOS
Transportable	HMMWV, UH-60	HMMWV, UH-60	HMMWV, UH-60	HMMWV, UH-60
Max System Weight	1500 lbs	1311 lbs	1487 lbs	1402 lbs
Deployment	2012	2012	2012	2012
Acoustic Profile	Near-quiet	Near-quiet	Near-quiet	Near-quiet
Fuel	Jet or Diesel Fuel	ICE Concept FC	Diesel Grade #2	Diesel and Jet

Table 11 Concepts Technical Information

Comparison Criteria	The Choctaw	The Mole	Chicken Hawk
Air Configuration	Co-axial blades	Synchropter Rotor System	Single Rotor with tail
Ground Configuration	Wheels	Three Wheels	4 wheel vehicle
Payload Mass, lbs	60	Max. 60	120
Gross Takeoff Weight. lbs	1033	1387	1249
Aero Propulsion Type	Zoche Diesel Engine	Zoche Diesel Engine	Zoche Diesel Engine
Energy Source for Air Transport	FC or Ultracapacitor	Deisiel Grade #2 (10 Gals)	Diesel Engine
Ground Propulsion Type	4 Electric Motors	DC Electric Motors	Electric
Energy Source for Ground Transport	FC or Ultracapacitor	Batteries	Batteries
Hovering Power, hp	105	137	137.5
Cruise Power, hp	66	40	83
Basis of Autonomous Control	CPU	MIAG	Internal CPU
Primary BLOS Method	Ethernet Wavelan	CDL Class IV/V SATCOM	Satellite Radio
Primary Navigation Method	DGPS	DGPS/Terrain Map	GPS
Primary Sensor Type	Wescam Suite	DVAL FLIR/CLD Cameras	FLIR Camera
Chemical/Biological Sensor	FLAPS	Air: Customer Specified Package Ground: Lab-On-A-Chip	Acoustic Wave Sensors
Method of Sling Attachment		Four latch system on the Air Unit	Points at main rotor hub and vehicle base (4)
Method of Deploying Payload at range	Thru roll-up doors	Pulley and Latch system	Manual Access through Door
Enabling Technology	FC Development	Existing	Existing Technologies
Overall Dimensions, Stored, ftxftxft	7fx 3.5 x 9	7.57x4.94x3.82	4.2x7.1x7.3

6.2 Chicken Hawk Summary

In accordance with the CDD, the UHV is able to perform the Baseline Mission Profile illustrated in Figure 6. The Chicken Hawk is able to operate at an altitude of 4000 feet with a maximum temperature of 95°F. And it is capable of achieving a VROC of between 200 to 500 fpm.

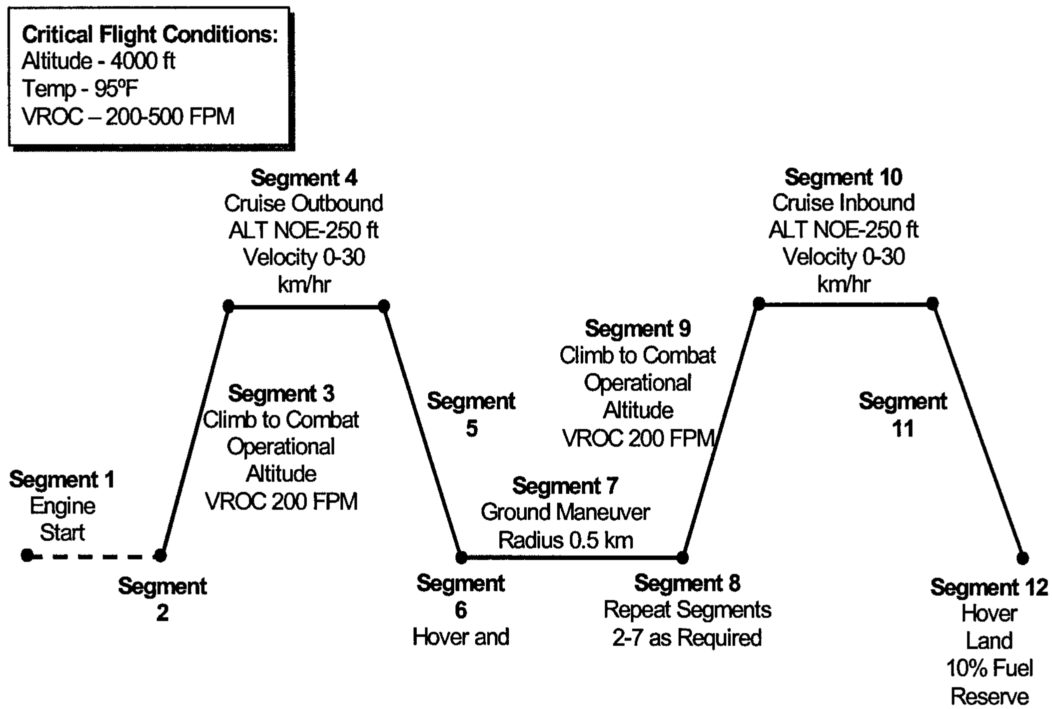


Figure 6 Baseline Mission Profile

The Baseline Mission Profile is accomplished by the Chicken Hawk by the following steps. In segment 1, the Chicken Hawk is allowed 5 minutes to warm up in idle, this is to allow the engine to reach a steady state condition to allow most efficient use of the engine power. In segment 2, the Chicken Hawk goes to a hover position in preparation for a vertical climb. The Chicken Hawk is allotted 2 minutes for hovering at this point. In segment 3, the Chicken Hawk performs a vertical climb to the combat operational altitude of 250 feet. The vertical rate of climb for this section is 500 fpm. Based on these requirements it takes about half a minute for the Chicken Hawk to reach the operational altitude. In segment 4 the Chicken Hawk is ready to cruise outbound to the operational range. This is performed at NOE at a maximum velocity of 30 km/hr. The CDD requires that the time of flight to the operational range be 30 minutes or less. Therefore the distance to the operational range is 15 km. In segment 5 the Chicken Hawk descends in preparation for the beginning of the ground maneuvers. The descent is performed using the same VROC as with the climb. The time required to perform this operation is half a minute as well. In segment 6 the Chicken Hawk performs a hover and landing maneuver, which takes approximately 2 minutes.

After the Chicken Hawk is on the ground, the engine, which is the power supply for the aerial vehicle, is shut down. Then the ground vehicle, which is powered by self-contained batteries and electric motors, exits the aerial vehicle. Now the UHV has separated into an UAV and an UGV. Although the UAV is non operational in the physical sense in this scenario, the avionics are still operational using battery supply. This is done to satisfy the requirements of the CDD. As will be seen later, this vehicle is capable of performing more missions, which involve the UAV operating during the UGV maneuvers. In segment 7 the UGV travels for 0.5 km at 6 km/hr. This takes approximately 5 minutes. Once the UGV reaches 0.5 km, the payload is delivered and the UGV returns to the UAV. The UGV is capable of traveling on terrain that is composed of unimproved roads, which could have a grade of no more than 12 degrees up or down and particles that have no more than a RMS of 1 inch. This is a total round trip of 10 minutes and 1 km, however the UGV is capable of traveling for no less than 2 hours. Once the UGV returns to the UAV and docks, the Chicken Hawk starts the cycle for returning. Although there is not a segment shown for warm up and idle, because the engine was shut off there is 5 minutes allowed for warm up and idle. In segment 8 the Chicken Hawk performs a take off and hover. In segment 9 the Chicken Hawk performs a vertical climb to the operational altitude. In segment 10 the Chicken Hawk cruises inbound returning to the initial starting point. In segment 11 the Chicken Hawk descends for hover and landing operation. And in segment 12 the Chicken Hawk hovers and lands, with a 10% fuel reserve.

While on the battlefield during all operations the Chicken Hawk is capable of sensing weather, chemical/biological weapons, and friendly or foe targets. All of these operations are performed by the avionics/electronics systems. The specific purposes and capabilities of these systems are discussed later. In addition, the Chicken Hawk is capable of carrying a minimum payload of 60 pounds during all operations.

As mentioned before, the mission step through described previously is only based on the Baseline Mission Profile and the CDD requirements. However this vehicle has several applications that go far beyond the CDD requirements. All of these applications stem from the fact that this vehicle is two in one. It takes all of the capabilities of a UAV and UGV and puts it into one. The most important aspects of this vehicle occur during the ground maneuver, when the Chicken Hawk is separated into the UAV and the UGV. During this time it is possible for the UAV to perform separate missions while the UGV is deployed. For example the UAV could travel back to the home base and retrieve more UGV's to bring to the operational range for deployment. It is also possible because of this separation that in case the UGV is lost the UAV can return to the base. This way there is less cost involved in case the UHV is damaged. Table 12, gives the ranges and endurances for two scenarios based on the baseline fuel load of 53.78 lbs (7.38 gallons) and the maximum fuel load of 93.24 lbs (20 gallons).

In Table 12, two scenarios are compared for the different fuel loadings. The baseline fuel load and the maximum fuel load. Scenario A is if the UHV is allowed to takeoff and cruise at 30 km/hr until there is 10% of the beginning fuel load remaining. Scenario B is if the UHV is allowed to takeoff, climb to operational altitude, and hover until there is 10% of the beginning fuel load remaining. It's key feature can be seen in Figure 7 which was drawn using CATIA.

Table 12 Range and Endurance for two scenarios

Fuel Load (lb)	Scenario	Range (km)	Endurance
53.78	A	64.22	2.14
53.78	B		1.10
93.24	A	111.35	3.71
93.24	B		1.91

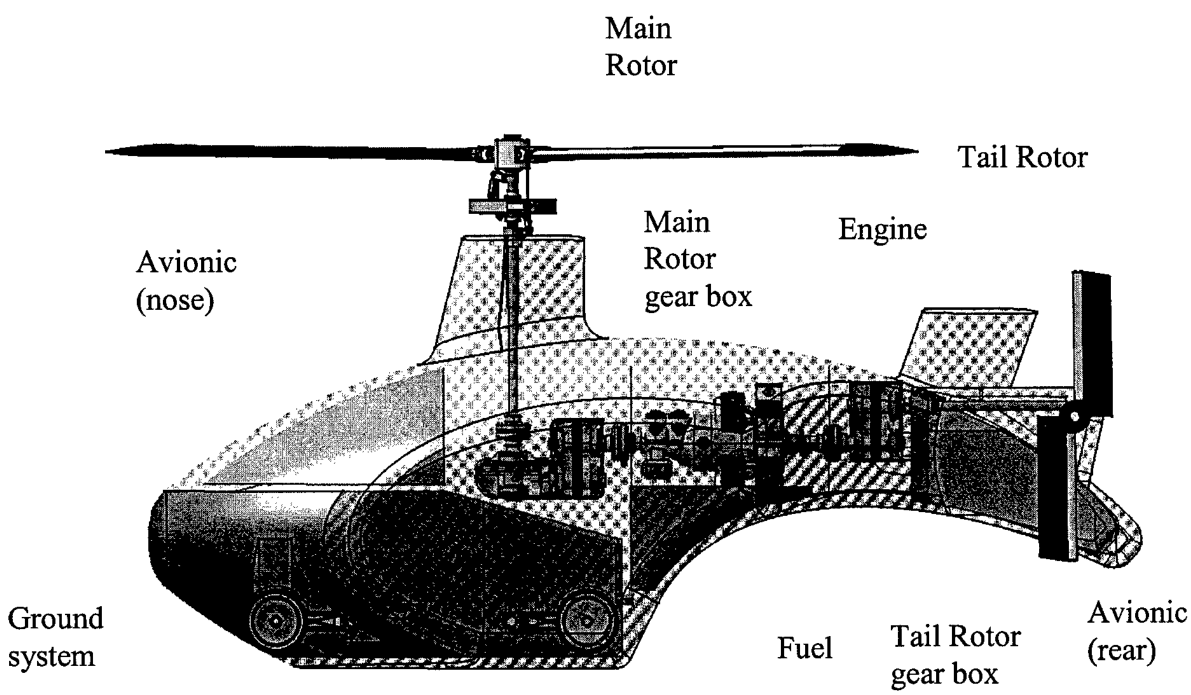


Figure 7 Key Features of the Chicken Hawk

Table 13 Selected Concept Evaluation

CDD Requirement	Requirement	Assessment	Remark
Payload	60 lbs	**Exceeds**	**Can carry 120 lbs**
Endurance	4 hours	**Meets**	
Flight Profile	Hover-Full	**Meets**	
Vertical Climb	200 fpm	**Exceeds**	**Can climb at 500 fpm**
Operational Altitude	0 – 250 ft AGL	**Exceeds**	
Airspeed	30 km/HR	**Exceeds**	**Can cruise at 259 km/hr at full power**
Ground Speed	6 km/hr	**Meets**	
Operation	Semi-autonomous	**Meets**	
Communication	BLOS	**Meets**	
Transportable	HMMWV, UH-60	**Meets**	
Max System Weight	1500 lbs	**Meets**	**Total system weight =1402 lbs (wet)**
Deployment	2012	**Meets**	
Multiple Mission Profiles	Can carry out multiple mission profiles	**Meets**	

Table 13 summarizes the estimated performance of the Chicken Hawk in reference to the major aspects of the Concept Description Document. The vehicle meets or exceeds all the major requirement of the CDD.

6.3 The Implementation

Final planning and design for the Chicken Hawk should begin now in order to ensure successful completion of the project by the year 2012. This system uses existing off the shelf hardware and proven systems. By modifying and improving proven technologies, AMCOM will receive the maximum vehicle for the minimum price. To develop non-standard technologies, while providing for an advanced system, will drive development costs much higher as well as possibly lengthening the development timeline.

Since the Chicken Hawk does not rely on anything to be invented, the design process can move from design to system integration and prototyping much faster than if new components had to be developed on their own. This in turn allows for a longer testing and evaluation period before full-scale production and subsequent deployment begins. By doing this, the system has a much higher chance of meeting the mandated 10-year timeframe, as shown in Table 14, with ample time for testing and training personnel on the system, as well as having more of the "bugs" worked out of the system. By providing a way to carry out a variety of missions in a reliable system, the Chicken Hawk will be an invaluable tool on the battlefield of the future.

Table 14 Programmatic 10 year schedule

Contract Start	2002
Development of Design	2003
Manufacturing of prototype	2004-2005
Testing prototypes	2005-2007
Redesign after testing	2007
Full manufacturing run	2008-2012
Units in field	2011-2012

The primary risk associated with this project comes in the first five years of the project. Scheduling technology developments is not an exact science. The phases of this cycle can and will very likely overlap and not be constrained by the indicated schedule. After this initial cycle, the remainder of the project's life such as manufacturing, operations, and disposal will likely follow the indicated schedule, barring discontinuance of the project at some point.

The transmission system is also considered a risk. The system can be bought off the shelf but some aspects of the system may have to be reconfigured to work in this design. This could delay production minimally.

Due to the amount of internal logic, the vehicle must have software development extended to ensure proper vehicle function.

The UHV design that is eventually produced and deployed will combine the capabilities currently performed separately by UAV's and UGV's. This will reduce operating and support costs significantly, by reducing the number of personnel and the amount of training currently needed to field both UAV's and UGV's. The UHV will be have an advantage in certain mission areas commonly categorized as "the dull, the dirty, and the dangerous". That is, it will be able to monitor a much larger area than human sentries and thus become a force multiplier. It can be used to detect for nuclear, biological, or chemical contamination without risk to human life. The UHV will also be capable of assuming risky missions and can be used to prosecute heavily defended targets (currently left to forces on the ground or in the air) without loss of human life. In short, the opportunities available in effectively deploying the UHV are subject only to the imagination of the commanders.

The UHV will probably cost as much to develop as current manned air and ground vehicles. However, the cost of the UHV will be significantly cheaper over the entire life cycle. This is due to the fact that personnel can be sufficiently trained with simulators, unlike currently manned vehicles where some losses occur during training. There is no threat to the personnel if the UHV is lost during a mission. This will reduce the number of crews that have to be trained as replacements, thus saving time and money.

The Chicken Hawk meets the Army requirements and should be deployed in the year 2012.

6.4 Assessment of Selected Concept

This section gives recommendations for the selected concept for future developments. Appendix F presents the detailed comments provided by the professors and mentors.

Systems Engineering:
Since the development of this project would likely involve suppliers and contractors for the aviation and robotics community, we recommend that several system-level practices be refined for the next phase of the project. The project and its requirements should be transitioned to a consistent set of units. The current project framework has several unit conventions that are familiar to customers and users, but could produce technical errors in the further development and execution this system. This development would also include a standard set of acronyms and symbols so that the future team could communicate precisely in technical terms. The customer and system integrator could also develop more precise definition of performance points on the baseline mission so that different studies can be compared with consistency.
On the technical side, the overall configuration of the vehicle as presented is slightly different in the pictures than in the analysis. The final drawings appear to be one iteration behind the analysis and discussion with the payload being too far forward to provide static balance when removed. The configuration of the overall systems should be refined as implied in the word of the report.

Aerodynamics:
As recommended in the report, a co-axial rotor configuration would require significantly less power that the single rotor and the tail rotor. Servo flaps could reduce the hub linkage strength and mass requirements. Servo flaps also help provide some recovery margin in the case of an engine failure. The tradeoff between these systems should consider the mission capability and the programmatic implications the various rotor configurations.

Mission Simulation:
The mission simulation for the vehicle can now be refined and expanded. The first area to look at is the ground mission. Because the detailed are scarce in the concept presented, a new set of power, weight, and motor designs should be completed to determine the impact on vehicle weight. The simulations should include the maximum range and endurance of the ground vehicle. The complete mission scenario could be expanded to explore broader possibilities of the two-piece concept. This could include the deployment of multiple ground robots by multiple air ships and the interaction of this information in various battlefield scenarios.

Mechanical Configuration/Structures:
The structural estimations were the weakest component of the analysis. Calculations should be performed to verify the support member cross sectional areas and wall thicknesses. The possibility of developing parametric weight equations using the next iteration of the design as a baseline would allow system level trade studies to be effectively performed to refine the configuration.

Propulsion:
The engine selected should be investigated in some detail to verify it maturity and performance for this application. Currently, the engine information consists of one web page. While the information was sufficient for the preliminary concept, no independent verification or current user could be cited of found. From the information available, the are several issues that should be address. Engine cooling is stated to be installation dependent. Since this engine appears to be developed for turbo props, the helicopter installation must be carefully considered. Using diesel fuels has implications on the low-temperature starting required in the CDD. The shaft speed and output power should be reanalyzed to insure compatibility over the flight envelope. The engine is also listed as an air start. This subsystem need to be investigated in more detail.
The supplies should be asked for independent verification of the engine performance claims or bring the engine to a government facility to verify its performance. Since the engine supplier is international; a sole source for this engine would be a programmatic consideration as well.

Ground Robotic and Avionics
Most of the technology is feasible based in existing hardware/software capabilities. However, some technologies may require further demonstration. Consider including the following capabilities from the IPT 2 vehicle into the selected concept: (1) Common Data Link (CDL) systems and available Tactical Common Data Link (TCDL) systems for communication; (2) RVM-based terrain following system; (3) Sandia Laboratory Lab-on-a-Chip for Chemical/Biological Detection; (4) and MIL-1553B interfaces. These technologies would enhance the selected configuration

Programmatic Considerations:
The Programmatic work strongly indicates that an Initial Operational Capability of 2012 is a very ambitious goal. The integration of this vehicle will require supplier who do not normally interact to work together. Therefore, a design study that involves the potential supplier, contractors, and system integrates is warranted immediately to begin the processes. Further, a specific strategy is needed to be selected for the development and deployment process. If the system follows the standard Army development process, it will likely become very expensive to operate and maintain. Another approach would be a DARPA or more research oriented demonstration program that had the goal of a more autonomous, low maintenance operations scenario.

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Appendix A - Concept Description Document

Concept Description Document Approval

The undersigned agree that the attached Concept Description Document as marked will be the basis the UAH IPT 2002 Design Competition. From this time forward, any questions or clarifications concerning the concept description document to the Customer shall be submitted in writing and the answer distributed to all UAH IPT's in writing.

To change the Concept Description Document Prior to April 30, 2002 shall require that the change be stated in writing and that a person authorized by every one of the signers below endorse the change with their signature. The revision will be labeled uniquely and distributed to all teams simultaneously.

The original of this document will be kept on file with the UAH Project Director. All signers will receive a copy of the original document.

James P. Winkeler, 2/5/02
James Winkeler, Customer

02/05/2002
Geof Morris, UAH IPT 01

Dana Quick, 02/05/02
Dana Quick, UAH IPT 02

Jennifer Pierce, 2/5/02
Jennifer Pierce, UAH IPT 03

Robert A. Frederick Jr., 2/5/02
Robert A. Frederick, Jr., UAH IPT 2002 Project Director

1. General Description of Operational Capability

1.1. Overall Mission Area

1.1.1. The system shall be a versatile scout and pack animal for future force structures, transporting critical payloads (e.g., ammunition, medical supplies).

1.1.2. The system shall be capable for use for target recognition and definition.

1.1.3. The system shall be capable for use in terrain definition.

1.1.4. The system shall be capable for use in situational awareness.

1.1.5. The system shall be capable of at least semi-autonomous operation, with full autonomous operation desirable.

1.1.5.1. The system shall be capable of human interface as required.

1.1.6. The system shall be capable of executing both a preplanned and diverted mission profiles.

1.1.7. The system shall be capable of navigating and functioning without a payload.

1.1.8. The system shall be capable of detecting chemical and biological threats.

1.1.9. The system shall be capable of detecting adverse weather conditions.

1.2. Operational Concept

1.2.1. The system shall be capable of nap of the earth flight (below the treeline).

1.2.2. The system shall be capable of operation at a range of 15-30 km ahead of the fighting force, with a 10% fuel reserve upon return.

1.2.2.1. The system shall be capable of gathering information on threat activities at range.

1.2.2.2. The system shall be capable of enhancing the RISTA/BDA.

1.2.2.3. The system shall be capable of transmitting information via secure data links and C2 structures BLOS.

1.2.2.4. The system shall be capable of using TF/TA/GPS/INS hardware and software to define and navigate complex terrain.

1.2.2.5. The system may encompass a degree of AI, ATR, and on-board decision making.

1.2.3. Payload Requirements

1.2.3.1. The system shall be capable of carrying a payload of 60lbs required gross weight, 120lbs desired gross weight, with a minimum payload volume of 2' x 2' x 2' [8 ft^3].

1.2.3.2. The system shall be capable of flying the payload to operational range in 30 minutes or less and be able to return from range in 30 minutes or less.

1.2.3.2.1. The vehicle will have a minimum cruise airspeed of 30 km/hr and a desired airspeed of 100 km/hr.

1.2.3.3 There shall be no power or data interfaces between the vehicle and the payload.

1.2.4. Mission Requirements

1.2.4.1. The system shall be capable of landing in an unprepared area with a ground slope of 12° maximum up or down.

1.2.4.1.1. The vehicle must have vertical takeoff and landing capabilities.

1.2.4.2. The system shall maximize survivability.

1.2.4.2.1. The system shall have a near quiet acoustic signature.

1.2.4.2.2. The system shall be designed for an operational altitude of 0 – 250 ft AGL required, 0-500 ft AGL desired.

1.2.4.2.3. The system shall be capable of a 200 fpm VROC [required], 500 fpm [desired], at 4000 ft and 95 °F, with the payload in place.

1.2.4.3. The system shall be designed to be transported via a HMMWV and trailer, and/or via external sling load by a UH-60 helicopter.

2. System Capabilities
   2.1. The system shall be capable of operation at an altitude of 4000ft, 95 degrees Fahrenheit ambient temperature, and not using more than 90% maximum rated power.
   2.2. Operational Performance
      2.2.1. The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse environmental conditions worldwide, down to –40 °F.
      2.2.2 The system shall possess essential performance, maintenance, and physical characteristics required to operate under adverse geographical conditions worldwide.
      2.2.3. The system shall be capable of operating from any unimproved land facility surface day or night, including low illumination.
      2.2.4. The system shall be capable of operation under and detection of battlefield obscurants.
      2.2.5. The system shall be capable of ground operations on unimproved roads at ground speeds of 6 km/hr [required], 12 km/hr [desired] for no less than two (2) hours at a radius of 0.5 km [required], 1 km [desired]. Unimproved roads: Non-prepared surfaces, not to have more than RMS of 1", which means, over 1 ft can not rise or dip more than one inch, no linear features, which means no barriers, blocks, bricks, big rocks, etc., nothing in path of vehicle except trail or road and finally, no more grade than 12 degrees.
      2.2.6. The system [vehicle and ground station] shall weigh no more than 1500 lbs [required], 1000 lbs [desired].
      2.2.7. The system shall use readily available diesel or jet fuel.
   2.3. The system shall possess the following electronic capabilities:
      2.3.1. Mission Planning System
         2.3.1.1. The system shall possess a point-and-click pre-mission planning system to simulate mission flight.
         2.3.1.2. The system shall possess data loading capabilities.
         2.3.1.3. The system shall be capable of coordination and reaction to immediate operational mission changes.
         2.3.1.4. The system shall be capable of processing self awareness and threat sensor inputs.
         2.3.1.5. The system shall be capable of enabling TF/TA from digital mapping information from satellite or other sources.
      2.3.2. Avionics
         2.3.2.1. Communications and navigation suite architecture shall be compatible with emerging military data links.
      2.3.3. Communications
         2.3.3.1. System communications shall be robust and have clear secure modes of operation
         2.3.3.2. Communications shall be simultaneously LOS and BLOS which can include satellite relay or other relay system compatibility.
         2.3.3.3. System must posses IFF and be compliant to all FCC/military communication regulations.

2.3.3.4. System must be capable of communication with and sharing digital mapping/targeting information with other DoD RISTA platforms.

2.3.4. Connectivity

2.3.4.1. The system shall be interoperable with other DoD systems envisioned for the 2012 battlefield to the maximum extent possible and be compatible with service unique command, control, and information systems.

APPENDIX B BASELINE REVIEW CHARTS

UAH

ESTACA

IPT 2002 Baseline Review

The University of Alabama in Huntsville

and

Ecole Superieure des Techniques Aeronautiques et de Construction Automobile

January 31, 2002

Outline

UAH

- Purpose
  - Establish CDD and a Baseline Configuration
- Main Points
  - Course Overview
  - Concept Description Document
  - Existing Systems
  - Baseline Design
  - Final Recommendations

1/31/2002 IPT2002 Baseline Review 2

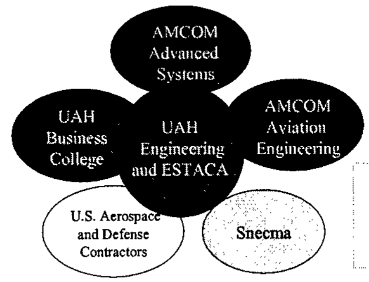
UAH

ESTACA

Course Overview

UAH IPT 2002 Project

UAH



Unmanned

Hybrid

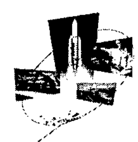
Vehicle

1/31/2002 IPT2002 Baseline Review 4

Engineering School

- Founded in 1925
- Located in Paris

  Additional site in Laval (expected September 2003)
- Enrollment of 1000 students
- A 5-year graduate program
- Aeronautical, Automotive,
- Space & Railway Engineering
- 180 graduates annually



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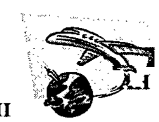
Schedule

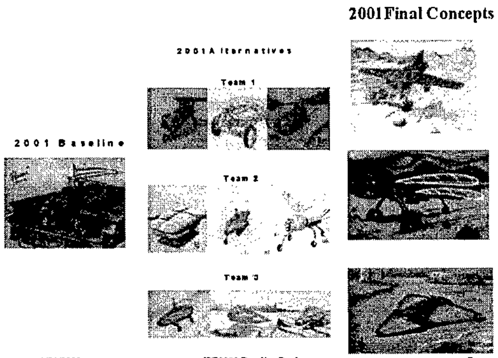


Phase III
- Final Concept
- IPTs
- Competition

Phase II
- Three Alternatives
- IPTs
- Competition

Phase I
- Baseline
- Superteam
- Cooperation

1/31/2002 IPT2002 Baseline Review 6



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Discipline	Name/Email	Team 1	Team 2	Team 3
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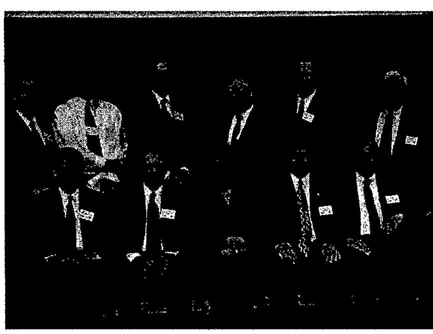
	John Fulda			
	Mick Cordiat			
	Al Reed			
	Robert Frederick			
Systems Engineering	Timothy Hughes	Jamie Flynt	Randal Holt	Brian Akins
	Robert Frederick			
Aerodynamics	John Berry	Forrest Collier	Amber Williams	Adam Elliott
Propulsion/Drive	Bernard Acker	Florence Bert	Paul Chesuvau	Dorothee Barre
		Claire Lessiau	Mathieu Pernet	Thomas Clerc
		Alexandre Tellie	Arnauld Souchard	Samuel Glemee
Ground Robotics	Susan Gamble	Jason Maycock	Levi Gabre	Gregoire Berthiau
	Jim Dinges			
Mission Simulation	Brad Miller	Shane Mills	Tammy Jackson	Christina Davis
Mechanical Configuration	Kevin Rotenberger	Kari Selomaa	Curt Kincaid	Patrick Damiani
Structures	Alex Maciel			
Avionics, Sensors,	Lew Williams	Teresa Samuels	April Burgess	Michael Burleson
Automous Flight Controls	Joe McKay	Isabel Ortega	Josh Freeman	Claudio Estevez
Programmatics	Tim Hughes	Geof Morris	Curt Kincaid	Jennifer Pierce
	Pat McGinnis			

UAH

1/31/2002 IPT2002 Baseline Review 8



UAH

1/31/2002 IPT2002 Baseline Review 9

Concept Description Document

UAH

- Purpose
  - To Establish Customer Wants and Needs
  - To Establish Guidelines for the Competition

1/31/2002 IPT2002 Baseline Review 11

Motivations

UAH

- Reconnaissance
- Chemical/Biological Detection
- Delivery of Critical Cargo
- Target Recognition and Designation
- Terrain Definition
- Situational Awareness
- Communication/Data Relay

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System Capabilities

UAH

Parameter	Required	Desired
Airspeed	30 km/h	100 km/h
Vertical Climb	1000 fpm	1500 fpm
Ground Speed	6 km/h	12 km/h
Flight Profile	Hover-Full Flight	Hover-Full Flight
Operational Altitude	0-250ft AGL	0-500ft AGL
Endurance	4 hrs	6 hrs

1/31/2002 IPT2002 Baseline Review 13

System Capabilities

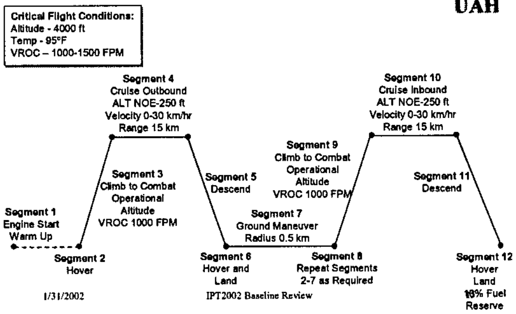
UAH

Parameter	Required	Desired
Payload	60 lbs	120 lbs
Range	15 km	30 km
Ground Radius	0.5 km	1 km
Operation	Semi-Autonomous	Autonomous
Transportable	HMMWV Trailer	HMMWV Trailer
	UH-60 Sling	UH-60 Sling
Max Weight	1500 lbs	1000 lbs

1/31/2002 IPT2002 Baseline Review 14

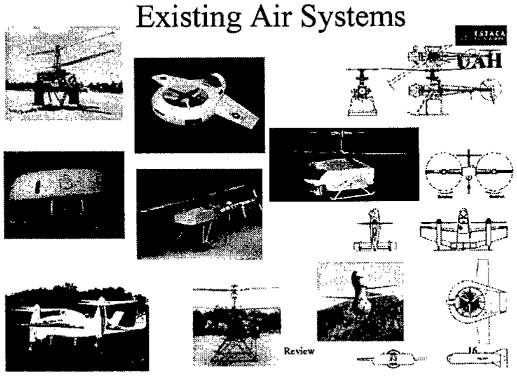
Hybrid UAV/UGV Baseline Mission Profile

UAH



Existing Air Systems

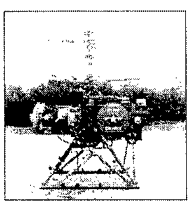
UAH



Review

System Assessment – QH-50B

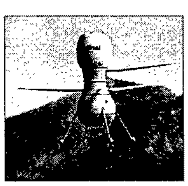
UAH



- Strengths
  - \+ Payload (543 lbs)
  - \+ Air speed (116 km/h)
  - \+ Altitude (8,600 ft)
  - \+ Weight (1,500 lbs)
- Weaknesses
  - – VROC (640 fpm)
  - – Autonomy (1 hr)

System Assessment – The Sentinel

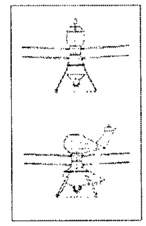
UAH



- Strengths
  - \+ Payload (231 lbs)
  - \+ Air speed (157 km/h)
  - \+ Altitude (11,500 ft)
  - \+ Weight (770 lbs)
  - \+ Autonomy (6 hrs 25')
- Weaknesses
  - – Installation of the payload

System Assessment – The Puma

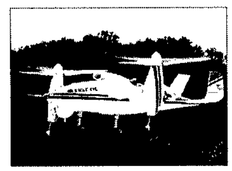
UAH



- Strengths
  - \+ Air speed (233 km/h)
  - \+ Altitude (18,000 ft)
  - \+ Weight (750 lbs)
  - \+ Autonomy (7 hrs)
- Weaknesses
  - – Payload (102 lbs)

System Assessment – Eagle Eye

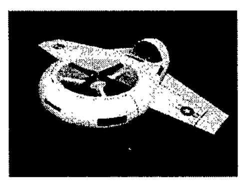
UAH



- Strengths
  - \+ Air speed (305 km/h)
  - \+ Altitude (14,000 ft)
  - \+ Payload (210 lbs)
  - \+ Autonomy (2 hrs 15')
- Weaknesses
  - – Weight (1,960 lbs)

System Assessment – The Cypher

UAH



- Strengths
  - \+ Air speed (130 km/h)
  - \+ Altitude (5,000 ft)
  - \+ Weight (250 lbs)
- Weaknesses
  - – Payload (50 lbs)
  - – Power (50 Hp)

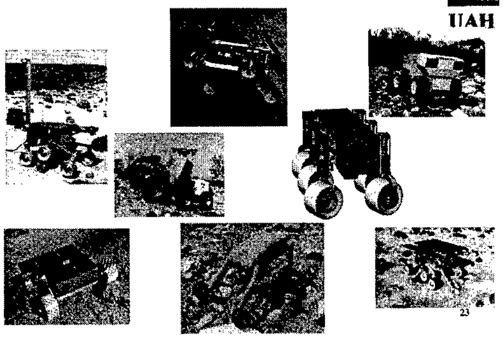
Evaluation of Existing Air Systems

UAH

	QH-50B	Sentinel	Puma	Eagle Eye	Cypher
Air speed : 30 km/h	◍	◍	◍	◍	◍
Vertical climb : 1000 fpm	●	◍	◍	●	●
Flight profile : hover/full flight	◍	◍	◍	●	◍
Endurance : 2 hrs	●	◍	◍	◍	●
Payload : 60 lbs	◍	◍	◍	◍	●
Vehicle weight : 1,500 lbs	◍	◍	◍	●	◍
Maximum altitude	◍	◍	◍	◍	◍
Range : 15km	◍	◍	◍	◍	◍

Existing Ground Systems

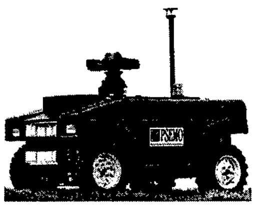
UAH



23

System Assessment –MDARS-E

UAH



- Strengths
  - + multi-threaded Obstacle Avoidance System
  - + Autonomous vehicle
  - + GPS-based Navigation System

System Assessment – RATLER Family

(Robotic All Terrain Lunar Exploration Rover)

UAH

- Strengths
  - + lightweight
  - + maneuverable
  - + navigate over long distances
  - + low thermal signature
  - + fuel cells source power
- Weaknesses
  - – payload

System Assessment – SANDDRAGON

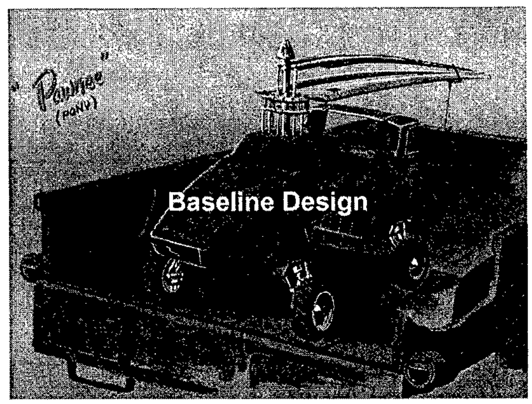
UAH

- Strengths
  - + high mobility
  - + maximum speed : 4.5 mph on level terrain.
  - + Payload max : 80 pounds in moderate terrain
  - + 5 hours endurance on average
- Weaknesses
  - – Low radio range

Evaluation of Existing Ground Systems

UAH

	MDARS-E	Ratler	Sanddragon
Ground speed : 6 km/h	◎	◎	◎
Ground Radius	◎	◎	●
Low Acoustic Signature	●	◎	●
Endurance : 2 hrs	●	◎	◎
Payload : 60 lbs	◎	●	◎
Vehicle weight < 1,000 lbs	●	◎	◎



Configuration Assumptions

UAH

- **Coaxial Rotors**
- **Assumed Gross Weight 1000 lbs**
- **4-Wheel, Electric Motors**
- **Payload in C.G.**
- **Rotors Fold**

Outline of Design Process

UAH

- 1. **Team** - Organize Team
- 2. **Spec** - Abstract Specification into 10 most important Evaluation Categories
- 3. **Config** - Assume a vehicle configuration, gross takeoff weight, and volume
- 4. **Aero** - Size rotors, determine power for VROC, Hover and Min Energy Cruise, assumed max lift, Cd, rotor area
- 5. **Subsystems** - Select 10 major subsystem components, estimate weight, volume, and power
- 6. **Power** - Select Power System for Rotors, Starter, Ground Robotics
- 7. **Mission** - Do First-Order Mission Analysis to determine energy/fuel mass requirements
- 8. **Layout** – Assume planform area, configure Vehicle Cross-Section with basic Subsystems, and estimate weight
- 9. **Eval** - Compare weight and performance parameters with CDD
- 10. **Recom** - Make Recommendations

Aero Power Estimations

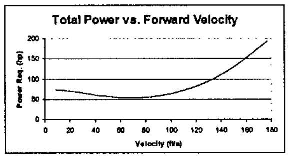
UAH

- For Forward Flight:

Total Power Req = $P_{induced} + P_{profile} + P_{parasite}$

Min. Operational Power
= 53 hp

Operational Velocity
= 76 ft/s
= 83 km/hr



Aero Power Estimations

UAH

•For Hover at 4000 ft:

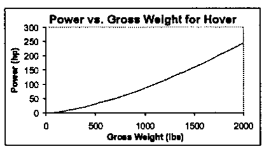
Thrust = (Gross Weight ÷ 2) = 500 lbs.

$P_i = (T_h^3/2\rho A)^{1/2}$ = 24.63 hp (for one rotor)

$P_{hover} = (P_i/FM)*2*K$

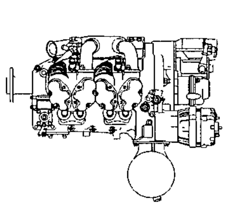
P_{hover}= 86.57 hp

Shaft
Speed = 604.16 RPM



System Assessment – IO-240B

UAH



- Strengths
  - + power
  - + Fuel consumption
  - + Shaft speed
- Weaknesses
  - – weight
  - – Weight to power

Evaluation of Existing Engine

UAH

	ROTAX 914 UL	IO-240B	TPJ-1304 HF	ROTAX 912 ULS	GEVAUDAN 9
Power	◍	◍	◍	●	●
Shaft speed	●	◍	◍	●	●
Weight	◍	●	●	◍	◍
Fuel Consumption	●	◍	◍	●	●
Weight to power	●	●	●	●	◍

Power

UAH

GROUND MISSION POWER REQUIREMENTS			
	WATTS	VOLTS	AMPS
AVIONICS	950	12	100
GROUND ROBOTICS	1440	36	40
TOTAL	2390	48	140
	System Battery Specifications		
	Kilowatt-Hrs	Volts	Amp*Hrs
Total Batt Specs:	18.36	48	810

Ground Robotics/Vehicle

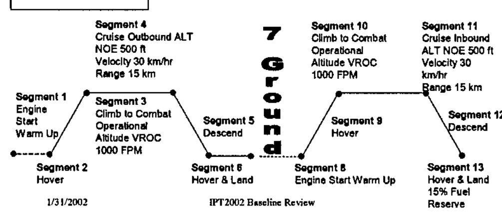
UAH

- Power Requirements
  - Four, 2 hp motors (one for each wheel)
  - Input: 36V and 40 A
- Weight (motors, wheels, etc.)
  - 200 lb
- Wheel Size
  - 10 in.

Mission Profile

UAH

Critical Flight Conditions
Altitude - 4000 ft. (Starting)
Temperature - 95°F
VROC - 1000 FPM



MISSION SIMULATION ASSUMPTIONS

UAH

- Modeled at 95°F: Hardest Operation (Worst Case)
- Starting Altitude – 4000 ft
- VROC – 1000 FPM
- Cruise Velocity, Range, Altitude – 30 Km/hr, 15 km, and 500 ft
- Fuel Mass Ratio – 5.8 lb/gallon
- FCR 15 gallons/hr @ 100% required power
- Mission segments Power Requirements:
  Warm-up 65% Hover 72.5% Climb 95%
  Cruise 75.2% Descend / Land 45%
- Total air time 2 hrs and ground time 2 hrs
- Ground Maneuver – electrical
- Fuel Reserve – 15%

Subsystem Weight Breakdown

UAH

Weight			
System	Components	Weight (lb)	
Aerodynamics	Rotor System, Aerodynamic Foils	100	lb
Avionics	Electronic Hardware, Sensor Arrays	115	lb
Ground Robotics	Suspension System, Motorized Wheels	200	lb
Mechanical	Chassis/Plating, Insulation, Battery Power	130	lb
Propulsion	Main Engine, Transmission	250	lb
Payload	Required Payload	60	lb
Fuel	Total Mission Fuel Requirement	124	lb
Batteries	Ignition Battery, Ground System Battery	72	lb
Vehicle	15% Contigency Weight	157.65	lb
Total Weight		1108.65	lb

Avionics & Sensors

UAH

- System Requirements
  - Communications:
    - Ground radio
    - Satcom
    - Data encrypting
    - GPS
    - Antenna
  - Control:
    - Gyro/inertial package
    - Sensors
  - Electronics:
    - CPU
    - Camera

Evaluation

UAH

Parameter	Required	Desired	Eval
Airspeed	30 km/h	100 km/h	Yes
Vertical Climb	1000 fpm	1500 fpm	Maybe
Ground Speed	6 km/h	12 km/h	Yes
Flight Profile	Hover-Full Flight	Hover-Full Flight	Yes
Operational Altitude	0-250ft AGL	0-500ft AGL	Yes
Endurance	4 hrs	6 hrs	Yes

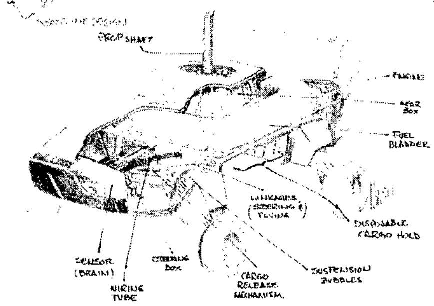
Evaluation

UAH

Parameter	Required	Desired	Eval
Payload	60 lbs	120 lbs	Yes
Range	15 km	30 km	Yes
Ground Radius	0.5 km	1 km	Yes
Operation	Semi-Autonomous	Autonomous	Yes
Transportable	HMMWV Trailer	HMMWV Trailer	Yes
	UH-60 Sling	UH-60 Sling	
Max Weight	1500 lbs	1000 lbs	Yes

Cross Sectional Layout

UAH



Development Schedule

UAH

- Assume Contract Start by Dec 2002
- Development of Design: 2003
- Manufacturing of Limited Run of Prototype(s): 2004-05
- Testing of Prototype(s): 2006
- Redesign after Prototype Testing: 2007
- Full Manufacturing Run: 2008-2012
- Units in Field: 2011-2012

Recommendations

UAH

- Refine subsystem weights
- Decrease max VROC
- Further assess existing systems
  - Sentinel
  - Puma
  - SandDragon

Recommendations

UAH

- Re-Evaluate
- Project found to be feasible; only requirement that may present problems is VROC= 1000 fpm
- *Recommend commencement of Phase 2*

APPENDIX C EVALUATION CRITERIA/JUDGING INSTRUCTIONS

As a recognized authority in your technical specialty by the UAH IPT Review Team Chairman, it is your responsibility to conduct a careful and thorough judging of three proposals. To provide a broad, impartial judgment, at least two other independent reviews of this paper will be made. The judging criteria contained herein are intended as both a guide for the judges and as an evaluation sheet for the student's paper. The judges should already be familiar with the detailed requirements of the Concept Description Document (CDD), which is Attachment 1.It is left to the judge's discretion to deviate high or low from the suggested point distribution. Please be aware that any additional comments you may care to make about the contents of the paper will be beneficial to the students.

The judges should review and score the applicable categories on this sheet before the final oral presentation. At the oral presentation, each team will make a time-limited, uninterrupted presentation. The Review Team will then have a timed question and answer period. Following all the oral presentations, the Review Team Chairman will ask for discussion and scores from each member of the Review Team. If the Review Team Chairman feels that the results represent the majority opinion of the Review Team, the scores will be passed to the IPT2002 Project Director. At this point, any deductions related to late submission or other factors are applied and the final scores are adjusted.

PROPOSAL INFORMATION
Project Name: *Unmanned Hybrid Vehicle (UHV)*
Team No: ____
Team Leader:

COMPETITION INFORMATION

Baseline Review: January 31, 2002

Alternative Concepts review: March 5, 2002

Submission of Final Proposal: April 23, 2002

Final Oral Review: April 25, 2002; 3:00 – 6:30

Awards Banquet: April 26, 2002; 11:00-1:00

SCORING Summary

Technical Content Final Grade ___

Organization/Presentation Final Grade ___

Originality ___

Application/Feasibility ___

FINAL SCORE ___

REVIEW TEAM CHAIRMAN	IPT 2002 PROJECT DIRECTOR
Virginia (Suzy) Young Acting Director, Advanced Systems AMCOM, Aviation and Missile R&D Center AMSAM-RD-AS Building 5400 Redstone Arsenal, AL 35898-5000 Phone: 256-876-3336 FAX: 256-876-8866 suzy.young@rdec.redstone.army.mil	Robert A. Frederick, Jr. Associate Professor Department of Mechanical and Aerospace Engineering THS231 5000 Technology Drive Huntsville, AL 35899 Phone: 256-824-7203 FAX: 256-824-7205 frederic@eb.uahl.edu

APPENDIX D REVIEW TEAM FINAL SCORING

TEAM1

CATEGORY	Pos	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7	Avg
Technical Content	35	30.45	30	26	32.9	30	29.4	33.6	30.34
Organization/ Presentation	20	17.8	18	19	18.4	16	15	19.2	17.63
Originality	20	19.2	19	15	18.2	18	16.8	18	17.74
Application/ Feasibility	25	21.75	20	10	20.5	17	20	23	18.89
TOTAL	100	89.2	87	70	90	81	81.2	93.8	84.60

TEAM 2

CATEGORY	Pos	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7	Avg
Technical Content	35	31.85	31	26	24.5	31	29.4	32.2	29.42
Organization/ Presentation	20	17	18	12	15.8	19	17	18.8	16.80
Originality	20	15.8	18	14	14.6	19	17.2	17.8	16.63
Application/ Feasibility	25	18	18	10	19	20	20	22.5	18.21
TOTAL	100	82.65	85	62	73.9	89	83.6	91.3	81.06

TEAM 3

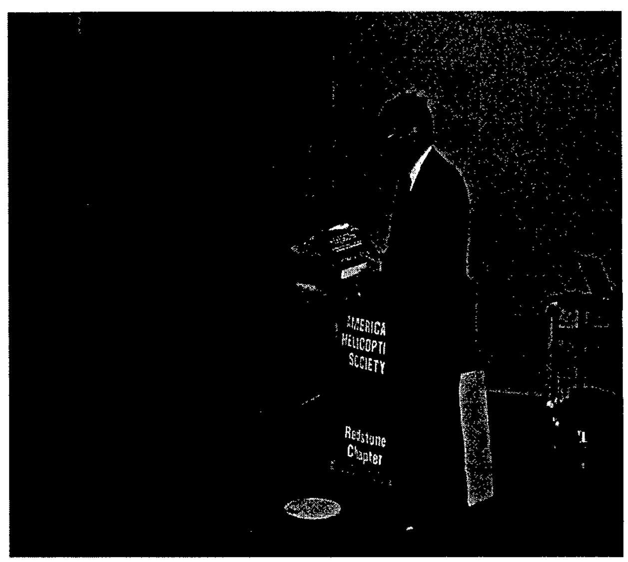
CATEGORY	Pos	Rev. 1	Rev. 2	Rev. 3	Rev. 4	Rev. 5	Rev. 6	Rev. 7	Avg
Technical Content	35	34.3	34	32	28.7	30	30.1	33.6	31.81
Organization/ Presentation	20	18.8	19	18	17.2	17	17.8	19	18.11
Originality	20	18.6	20	14	15.8	19	18.0	18.4	17.69
Application/ Feasibility	25	23.25	22	14	19.5	17	21.25	23	20.00
TOTAL	100	94.95	95	78	81.2	83	87.15	94	87.61

APPENDIX E AHS BANQUET PHOTOS

IPT 2002 AMCOM customer James Winkeler and Project Director Dr. Robert Frederick, Jr.

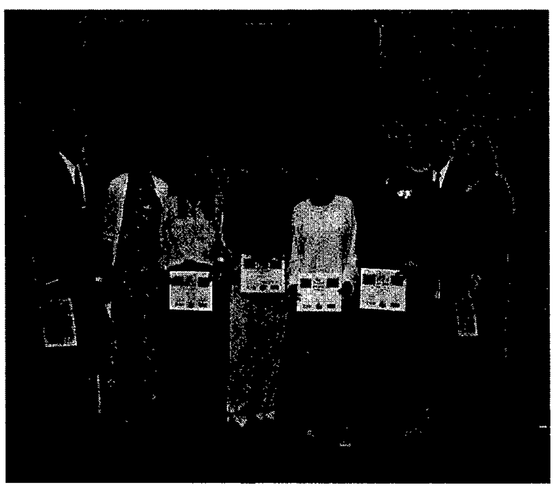
IPT 2002 Mentors: (Left to Right) Matt Tunstall, Alfred Reed, David Weller, Dr. Earl Wells, Dr. Charles Corsetti, Joe McKay, Mick Corgiat, Dr. Phillip Farrington, Bernard Acker, Alain Coutrot, Bradley Miler, Dr. Frank Franz, Dr. Dawn Utley, Marie-Sophie Pawlak, Dr. Robert Frederick, James Winkler, _, Rob Wentz

IPT 2002 Review Team and Faculty: William Gurley, SAIC; Doug Scalf, Quality Research; JC Hand, NASA Retired;Barry Basket, AMCOMl Dr. James Swain, UAH; Dr. Francis Wessling, UAH; Dr. Robert Frederick, UAH; Dr. Suzy Young, AMCOM.



In appreciation for being the ESTACA contact and for making all the travel arrangements, Dr. Robert Frederick awards Ms. Jamie Flynt a Mark's Engineering Handbook provided in memory of Dr. Zemke

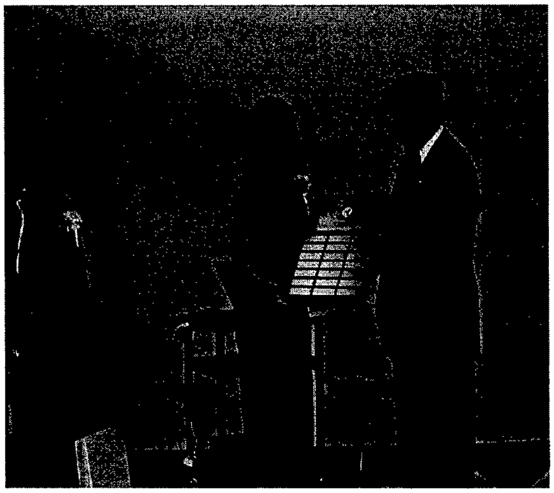
IPT 2002 Industrial and Systems Engineering Team: __, Angel Armstrong, Julie Fortune, Randal Holt, __, Dr. Robert Frederick, PJ Benfield



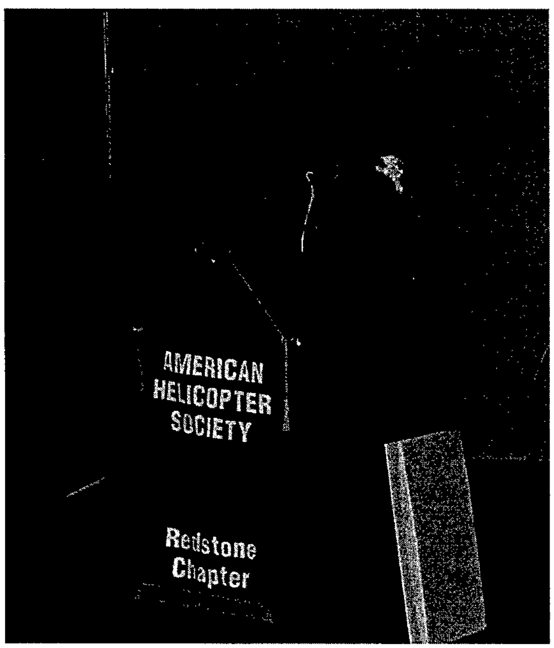
IPT 2002 Team 1: (From Left to Right) Jason Maycock, Teresa Samuels, Isabel Ortega, Kari Salomaa, Claire Lessiau, Geof Leader (Leader), Dr. Robert Frederick, Jamie Flynt

IPT 2002 Team 2: (From Left to Right) Amber Williams, Levi Gabre, April Burgess, Josh Freeman, Curt Kincaid, Matthieu Pamart, Tammy Jackson, Dr. Robert Frederick, Dana Quick (Leader)

IPT 2002 Team 3: (From Left to Right) Adam Elliott, Brian Akins, Patrick Damiani, Jennifer Pierce (Leader), Christina Davis, Michael Burleson, Dorothee Barre, Gregoire Berthiau, Dr. Robert Frederick



Jennifer Pierce receiving winner's plaque from __ while Dr. Suzy Young looks on.



Team 3 Leader Jennifer Pierce acceptance speech.

IPT 2002 Winners Team 3:

IPT 2002 Winners Team 3 and Distinguished Guests.

APPENDIX F VERIFICATION MEMOS

Date: May 28, 2002
To: Dr. Robert Frederick
From: Dr. Dawn R. Utley
Discipline: Systems Engineering
Subject: Validation and Assessment of IPT Reports

Technical Calculations:
The configuration drawings and the actual final configuration of the vehicle appear to be different. The CAD drawings are apparently one or two iterations from the final design. The reasoning for this is that the detachable ground unit is not centered in the vehicle and the weight does not appear to be balanced of the remaining components when the ground unit is detached.

Assessment of Selected Concept:
The customer and the teams used mixed units in their specifications and calculations. While there are no issues of incorrect conversions in the assessment of the reports, it does provide scenarios for problems. I recommend that future projects have a required consistent set of units in which results and calculations are documented. If other unit sets are more traditional for the particular discipline, the reporting of the results could be in dual units.

A standard set of acronyms and symbols would be helpful when comparing the reports. This would also simplify the report integration at the end. I recommend that systems engineering be tasked with establishing and managing these parameters in future projects.

The specification compliance matrices may not be at common conditions. For example, the air speed for Team 3 is listed as a much higher value that the other teams. In this case, the specification cited was the maximum speed of the aircraft. The other two teams appear to have cited the required speed as possible even though they did the simulations at other speeds. I recommend more precise definitions of performance points on the baseline mission for future studies to ensure consistency of results.

In future studies, it would be useful to have "top-down" specification accountability. This means that each specification is apportioned to the appropriate discipline as applicable and that each derived requirement is specifically traceable to the CDD.

Date: May 28, 2002
To: Dr. Robert Frederick
From: Dr. Dawn R. Utley
Discipline: Teaming Process
Subject: Validation and Assessment of IPT

The team of ISE graduate students who studied the teaming process throughout the semester presented a final report on their observations, empirical data collected from subjective test instruments, and comparisons between the teams.

Technical Calculations:
Each of the teams were assessed based on the following concepts: leadership, situational leadership ability and use, team culture, membership make-up, team progress, conflict management, communication styles, and collaboration with the international membership. Many of the empirical scores were not consistent with the observational data. The test instruments were not able to predict the MAE IPT winners. The observational data were the best predictors of success.

Assessment of Selected Concept:
Leadership that is conducive to sharing authority and responsibility was most successful. The leader's role of program manager and motivator proved to offer the winning team greater progress and success. Leadership must consider both personnel issues and productivity issues to accomplish the project goal. Cheerleading and motivation are as important as technical knowledge and expertise. Team culture and membership play an important role. The winning team had a greater number of proactive members, committed to the goal. Team progress observations showed that Team 3 was able to achieve a higher level of team performance then the other two teams. A team's ability to confront conflict, resolve it, and move beyond to achieve continued productivity is a factor in its success. While Team 2 had the greater conflict and confronted it appropriately, Team 3 was able to meet their confrontational challenges, resolve them and move beyond for greater results. Communications that are intense, open, meaningful, and respectful of each other tend to lead to success. This was evident in Team 3. While informal communication is better than stiff, formal communication, the mutual respect and intensity for ideas generated by the communication plays an important function. Collaboration between different cultures, languages and time zone can be a challenge. Success can be achieved from limiting expectations until a rapport is established, as was seen with Team 3.

Recommendations: A thorough understanding of the importance of team membership make-up needs to be communicated. The complete role of the leader should be stressed. There is a need to address both the technical performance issues and the personnel issues of coordination and motivation. An understanding of the teaming process and how to work through the stages of team development to move into real teamwork is essential. The importance of healthy communications, conflict management and collaboration of diverse groups should be acknowledged and practiced.
Date: May 28, 2002

To: Dr. Robert Frederick
From: Dr. Brian Landrum
Discipline: Aerodynamics
Subject: Validation and Assessment of IPT Reports

Technical Calculations:

Team 1: Narrative did not clarify that the Gross Weight (GW) used for the rotor sizing and power requirements was 1100 lbf, rather than 1311.7 lbf for the air vehicle **plus** the ground station equipment. The quoted power requirements (hover, forward flight, etc.) were not consistent throughout each of the analysis sections. The choice of a co-axial rotor system was admirable. However, a significant error was identified in the hover power calculation. The full GW rather than (GW/2) was used with a single rotor disk area. This resulted in a 41% over prediction of the required hover power. This error appears to have been propagated through the estimations of climb and forward flight power. The effect of the upper disk downwash on the lower disk aerodynamic performance was not addressed. No justification (or reference) for the body drag coefficient value of 1.2 was provided. Due to an incorrect conversion of velocity between ft/sec and m/s, the blade lift was under predicted by a factor of 91. This incorrect value was used to estimate blade deflection. Mixed units (metric and English) were used throughout the report, often in the same tables. This possibly contributed to the various miscalculations. The use of servo flaps is interesting. However, their effectiveness in a co-axial system was not discussed. Also the servo flap hinge moments should have been estimated to aid in the actuator sizing. The assumption of a constant tip speed and RPM at the various power levels should be addressed. Finally, at least a cursory assessment of engine out performance and how to compensate for disk torque in the event of a rotor failure would be appropriate.

Team 2: The assumptions used in the comparison between the co-axial and synchropter rotor aerodynamics and power requirements were not stated. It is not clear if the co-axial system was treated as two single rotors. Although GW/2 was used, the resultant hover power value could not be confirmed. It appears the power required may be slightly overestimated. There appears to be very little margin for growth in power requirements with the Zoche engine. The full Seddon and Newman reference was not cited and thus the synchropter equations could not be verified. The blade cant of 48° was not stated in the report body but was buried in an Appendix. However, it is not clear how the effect of cant angle on the vertical thrust component was used in the calculations of Appendix E (pages gg and hh). The power requirements were estimated based on GW = 1400 lbf. The actual flight weight should be 1100 lbf. Therefore, the calculated powers are probably conservative. The servo flap hinge moments should have been estimated to aid in the actuator sizing. The assumption of a constant tip speed and RPM at the various power levels should be addressed. Discussing the favorable response of servo flaps to compensate for engine failure was interesting. Addressing the rotor acoustic issues was a nice addition.

Team 3: This was the most traditional rotor design (single main with tail rotor). However, this team provided the least narrative details of the aerodynamic calculations. No iteration of rotor size was reported. Justification for the NACA 4421 airfoil was not provided. The atmospheric properties used in the performance calculations were not reported. However, the hover power value was confirmed based on properties consistent with the other teams. In addition to an 85%

figure of merit, another 90% factor was used. Plots of power required vs. flight speed were provided but not discussed. The overall disk size and blade chord were the largest of the 3 teams. This yielded the lowest and least efficient aspect ratio. A body drag coefficient of 1.5 is probably overly conservative. There cruise velocity and horsepower used in the mission analysis section were not consistent with values shown in the aerodynamic section plots. The assumptions used to estimate the power requirements of the co-axial rotor configuration were not reported. However, the lower power requirement in comparison to the single rotor was expected.

Assessment of Selected Concept:
The Team 3 design was by far the most traditional (single main plus tail rotor) from an aerodynamics perspective. Although this is the proven and reliable technology, consideration of newer technologies could significantly enhance the concept's performance. The aerodynamic calculations confirmed that a co-axial rotor configuration would require significantly less power than the single main plus tail rotor. Co-axial rotors are used in operational helicopters today. The transmission mass is probably lower for the co-axial system rather than the synchropter. Servo flaps could reduce the hub linkage strength and mass requirements. Servo flaps also help provide some recovery margin in the case of an engine failure.

Date: May 28, 2002
To: Dr. Robert Frederick
From: Brad Miller
Dr. Brian Landrum
Discipline: Mission Simulation
Subject: Validation and Assessment of IPT Reports

Technical Calculations:

Team 1: Didn't explicitly state some of the assumptions, especially type of fuel and fuel density. Fuel density is shown in Table E16, but is omitted on Table E15. Should have included SFC as part of Table 11, Engine Function Ratings on p. 34 (does show in Appendix E Tables 15 and 16). Calculations appear to be OK, with some questionable rounding. Other mission profiles/scenarios could have been examined to determine min/max performance capabilities such as potential maximum range and endurance at most efficient and least efficient engine speed conditions and min/max operational environment conditions (e.g. high/hot and sea level/standard). Did not have a mission simulation of the ground segment. Interesting to note that fuel density is significantly less than that used by the other 2 teams.

Team 2: Did excellent job of explicitly stating assumptions about fuel and fuel consumption rates. Excellent job of documenting best flight speed, ground segment battery power consumption, alternative scenarios, and determined max endurance. Hard to find anything wrong other than a couple of minor typos and lack of a ground segment mission simulation. Used highest fuel density of the 3 teams; may have been too conservative and erred on the high end.

Team 3: Did explicitly state assumptions about the fuel and fuel consumption. Could not find justification for a 108% power required during climb. This seems excessive and doesn't appear to be substantiated in the aeromechanics section. Did not investigate any alternative scenarios or determine max range/endurance capabilities (see comments on team 1). Did not incorporate ground mission simulations. Probably made the better set of assumptions on fuel characteristics.

Assessment of Selected Concept:

Though all 3 teams selected the same engine, their designs differed enough to yield different final results on power and fuel requirements. Team 2 was the only one to really go beyond the basic mission profile and try to determine the maximum capabilities of their design. All 3 teams made sure that they could perform the basic flight segments of the mission profile, but none of the teams adequately addressed the ground mission in their mission simulation and power/range calculations. It appears they over designed their battery requirements to cover the basic ground mission requirements and didn't get into what the impact was on total capabilities. In the future equal focus should be placed on the ground mission segments. Though the CDD was vague in this area, the teams need to make some assumptions and demonstrate what their design could do on the ground.

Date: May 28, 2002
To: Dr. Robert Frederick
From: Bradley R. Miller
Discipline: Mission Simulation
Subject: Validation and Assessment of IPT Reports

Technical Calculations:
Team 1: Didn't explicitly state some of the assumptions, especially type of fuel and fuel density. Fuel density is shown in Table E16, but is omitted on Table E15. Should have included SFC as part of Table 11, Engine Function Ratings on p34 (does show in Appendix E Tables 15 and 16). Calculations appear to be OK, with some questionable rounding. Other mission profiles/scenarios could have been examined to determine min/max performance capabilities such as potential maximum range and endurance at most efficient and least efficient engine speed conditions and min/max operational environment conditions (e.g. high/hot and sea level/standard). Did not have a mission simulation of the ground segment. Interesting to note that fuel density is significantly less than that used by the other 2 teams.

Team 2: Did excellent job of explicitly stating assumptions about fuel and fuel consumption rates. Excellent job of documenting best flight speed, ground segment battery power consumption, alternative scenarios, and determined max endurance. Hard to find anything wrong other than a couple of minor typos and lack of a ground segment mission simulation. Used highest fuel density of the 3 teams; may have been too conservative and erred on the high end.

Team 3: Did explicitly state assumptions about the fuel and fuel consumption. Could not find justification for a 108% power required during climb. This seems excessive and doesn't appear to be substantiated in the aeromechanics section. Did not investigate any alternative scenarios or determine max range/endurance capabilities (see comments on team 1). Did not incorporate ground mission simulations. Probably made the better set of assumptions on fuel characteristics.

Assessment of Selected Concept:
Though all 3 teams selected the same engine, their designs differed enough to yield different final results on power and fuel requirements. Team 2 was the only one to really go beyond the basic mission profile and try to determine the maximum capabilities of their design. All 3 teams made sure that they could perform the basic flight segments of the mission profile, but none of the teams adequately addressed the ground mission in their mission simulation and power/range calculations. It appears they over designed their battery requirements to cover the basic ground mission requirements and didn't get into what the impact was on total capabilities.

Overall Recommendations: Put equal focus on the ground mission segments. Though the CDD was vague in this area, the teams need to make some assumptions and demonstrate what their design could do on the ground.

Team 3 Recommendations: Go beyond basic mission profile and look at alternative scenarios. Determine maximum range and endurance possible. Make some assumptions and run specific ground segment mission simulations and determine maximum range and endurance on the ground and still be able to return. If anything, need to validate their battery power selection and power consumption requirements.

Date:	May 28, 2002
To:	Dr. Robert Frederick
From:	Dr. Brian Landrum
Discipline:	Mechanical Configuration/Structures
Subject:	Validation and Assessment of IPT Reports

Technical Calculations:

Team 1: As discussed in the Aerodynamic Assessment, the blade lift was under predicted by a factor of 91. This should produce a significantly larger blade tip deflection than quoted. However, the detailed equations used to make this estimate were not provided. The impact of the disk loading on the blade structural requirements was not addressed. Candidate materials for the frame and blades were identified including strength properties. However, no structural analyses (required frame tube thickness, blade skin thickness, hub forces, etc.) were provided. It was not clear how the material densities were used to estimate the various component weights. The spring-constrained blade that deploys under centripetal force was an interesting idea. Although the hinge pin was sized, the spring requirements were not addressed. The use of servo flaps was also interesting. However, the electric motor powered actuator weight was apparently drawn from a generic source. Actual actuator hinge moments and structural requirements should be estimated in the future. In general, the reliability of these novel features must be addressed before acceptance. Finally, failure modes and system compensation were not addressed.

Team 2: The mechanical configuration and structural calculation sections are very brief. Candidate materials for the frame and blades were identified including strength properties. However, no structural analyses (required frame tube thickness, blade skin thickness, hub forces, etc.) were provided. Disk loading and possibly estimated blade deflections should have been estimated. It was not clear how the material densities were used to calculate the various component weights. Actual servo flap hinge moments and actuator structural requirements should be estimated in the future.

Team 3: Dimensions for the fuselage frame support rods are provided. However, no justification is reported for the diameter in terms of structural strength requirements. There is no discussion of rotor blade structural requirements. Detailed component masses and their impact on the c.g. are presented.

Assessment of Selected Concept:

The structural estimations were the weakest components of the three team reports. In all cases candidate materials for the frame and blades were identified including strength properties. However, there are no supporting structural analyses. At a minimum, calculations to verify support member cross-sectional areas and wall thickness should be performed in the future. All three concepts use reasonably advanced materials. There is no proposed concept that stands out.

Date: May 29, 2002
To: Dr. Robert Frederick
From: Dr. Robert Frederick
Discipline: Propulsion
Subject: Validation and Assessment of IPT Reports

Technical Calculations:
I have summarized the propulsion-related parameters from the three teams in

Table 15. The teams provided similar parameters that vary logically according to the gross weight and rotor designs.

All teams chose the same make and model of power plant for the air mission. The information shows that the engine is an appropriate max power rating for the weight of vehicle that we are working with and a unique power range among its competitors. So I can comment on this engine for all the teams. Team 1 is the only team that added some weight for the engine oil. It appears that team 3 may have conservatively estimated the fuel consumption rate. This may be a residual for their curve fitting the two points from the specification sheet.

On the drive systems, not much detail is given on the method of determining the gearbox, shaft, and clutch weights.

Assessment of Selected Concept:
The maximum rating is within the envelope for the weight vehicles, and could possibly go to the 1500-pound weight maximum if the design grows. Some resizing of the rotor or lowing of the VROC to may be required accommodate this. The engine is radial so that vibrations are minimized.

The sole data on this engine is one web page. The list that the JAR-E and FAR 33 certifications are happening in 2002. They mention that the helicopter ratings will be "slightly reduced" in the web page. There are also some issues with cooling that are installation dependent that should be investigated. Using diesel fuels has some cold day start issues. I recommend asking this manufacturer some more specific questions about our application, either by phone or email. I have just started this process. Also, it would be beneficial to see if others have independently verified the performance claims of this engine before pursuing it further. From a programmatic point of view, an international sole source on the engine is an issue.

Another item to investigate in conjunction with aero is the shaft speed requirements over the flight envelope and see if the engine power/ power requirements, and shafts speeds are compatible over the operating envelope.

The engine is listed as an air start. More details on this would be helpful in determining trades for remote starting capability.

Table 15 Comparison of Propulsion/Drive Information from among the teams

Parameter	Units	Team 1	Team 2	Team 3
Gross Takeoff	lb	1067	1387	1249
Power to Climb	hp	125	137	147 (162)
VROC	fpm		500	500
Power to Hover	hp	106	137	130
Power to Cruse	hp	66	41	92
Optimum Cruise Velocity	km/hr	83	72	89
Engine Model		Zoche 01A	Zoche 01A	Zoche 01A
Engine Type		Two Stroke Diesel	Two Stroke Diesel	Two Stroke Diesel
Engine Output (Max)	hp	150	150	148
Engine Shaft Speed (Max)	RPM	2500	2500	2500
SFC (Max)	lb/hp hr	.365	.365.	.3855
SFC (Cruse)	lb/hp hr	.346	.346	
Fuels		Diesel#2, Jet Fuel	Diesel#2, Jet Fuel	Diesel#2, Jet Fuel
Baseline Fuels Weight	lb	64	52	54
Max Fuel Weight	lb	105	79	93
Engine Shaft Speed (Cruise)	RPM	NA	NA	NA
Rotor Shaft Speed	RPM	830	553	611
Tail Shaft Speed	RPM	NA	NA	2793
Engine Weight	lb	202	185[1]	185
Transmission	lb	77	40	118
Noise at 7 meters	dB	60-100	NA	NA
TBO	hours		2000	
Engine Reference Cited		None	www.zoche.de [2]	None

[1] Weight includes pneumatic starter, alternator, hydraulic Prop-Governor, Turbo- and supercharger
[2] Not cited in report, but in appendix

Date: May 28, 2002
To: Dr. Robert Frederick
From: Charles Corsetti
Discipline: Ground Robotics and Avionics
Subject: Validation and Assessment of IPT Reports

Technical Calculations:
I have attached my comments on the calculations and information contained in the IPT 2 and IPT 3 reports for the following areas: Ground Robotics and Avionics. In reviewing the IPT 1 report for the areas mentioned, I did not find many calculations or information on the how the calculations were made. In addition, IPT1 does not appear to present additional information for these areas that I would initially consider in the design of the UHV.

My comments on IPT 2 and IPT 3 point out what I believe to be errors made in the calculations presented, as well as noting where additional information should have been provided concerning the references cited. I have also provided a table that indicates the sections I reviewed in each report and contains the features of each design.

Assessment of Selected Concept:
In column 1 of the attached table I have included information on the IPT 3 design, while in column 2 I have included information on the IPT 2 design. In reviewing the cited references for both designs, I believe most of the technology is feasible based on existing hardware/software capabilities. However, some technologies may require further demonstration (Software and Computer Capabilities of the Ground Station of IPT 3; Chemical/Biological Detection of both IPT 2 and 3; and RVM capabilities of IPT 2).

I would consider including the following features of IPT 2 into the selected IPT 3 design: (1) Common Data Link (CDL) systems and available Tactical Common Data Link (TCDL) systems for communications (the latter, not mentioned in IPT 2 or IPT 3); (2) RVM based terrain following system (those elements that have been demonstrated); (3) Sandia National Laboratory Lab-On-A-Chip for Chemical/Biological Detection; (4) MIL-1553B interfaces. Including these IPT 2 features, I believe would result in the use of the best technologies.

Comments:

IPT 2:

2.5.2 Power calculation appears to be incorrect. I get 0.924hp based on the same assumptions in 2.5.2. No allowance is made for efficiency of the motors. Used wrong diameter (10 inches vs 8 inches) for the rear wheel.

2.5.3 Total weight calculation of 135 lbs appears to be inconsistent with other parts of the report. 2.5.2 indicates 300lbs (including 60lbs payload) and Table 16 indicates 251 lbs excluding payload and navigation/sensors.

2.7.1.1 MIAG (Modular Integrated Avionics Group) is manufactured by Lear Astronautics and is a component of Storm Shadow. Storm shadow is an unmanned strike fighter designed by Team Deception, a group of seniors in the Department of Aeronautical & Astronautical Engineering at the University of Illinois and completed in Spring 1998. RVM (Reconfigurable Vision Machine) is a project begun in 1994 at The Robotics Institute at Carnegie Mellon University. Micro STAR is manufactured by FLIR SYSTEMS.

2.7.1.2 CDL systems developed by L-3 Communications link to website doesn't seem to exist now. Rather TCDL (Tactical Common Data Link) is now linked. TCDL is also linked to the Federation of American Scientists website (www.fas.org).

IPT 3

2.4.1 Force calculations include a "static friction" term, which I believe should not be needed. Weight of the vehicle appears to be inconsistent even within section (419.05 lbs vs. 545 lbs). The efficiency calculation using 20 percent (or 80 percent loss) appears to be incorrect. Using a vehicle weight of 545 lbs and an efficiency of 30 percent (vs. 20 percent) I get a total power required of 5.6 hp. Electric motors need to be resized.

2.4.2 Batteries need to be resized for total power of 5.6 hp if calculations in 2.4.1 need correction. Also, may need to add 40 percent to total Ahr requirements for battery rating.

2.4.3 Revolution of wheels appears incorrect. I get 156.7 rpm. Gear reduction of about 25:1 at 4000 rpm motor output.

2.6.1.1 MACC is manufactured by Hamilton Standard Division of UTC and is a component of Storm Shadow. See comment in Section 2.7.1.1 of IPT2.

2.6.2.1 Ultra 7500 FLIR system is also a component of Storm Shadow.

IPT 3 PHOENIX TECHNOLOGIES	IPT 2 HYBRIDS R US	
2.4 Ground Robotics/Vehicle	2.5 Ground Robotics Vehicle	
2.4.1 Motors - Two electric motors -- 21 lbs (ea) -- 33 A at 24 VDC (ea) -- 0.75 hp (ea) - Total Force = 173.3 lbs - Total Power = 1.43 hp	2.5.1 Ground System Overview - Three-wheel, V-shape system - Two electric motors in back - Skid Steering	
2.4.2 Batteries - One 24 V, 109 Ahr - Seven 3.6 V, 41 Ahr - Total weight: 85 lbs	2.5.2 Power Required Calculations - Maximum Torque Cmax = 52.5 N-m - Maximum Power Pmax = 2.98 hp - Motors (2) -- 3300 rpm ea -- 13.2 N*m ea -- 8.5 N ea -- 2.2 kW total	
2.4.3 Wheels - Four wheels - 8-inch diameter - 4-inch width - 9 lbs (ea) - Turn at 511.2 rpm - Gear reduction 25:1	2.5.3 Ground Robotics Mass Definition - Motors (2): 76 lbs - Wheels: -- Front (1): 10 inches -- Rear (2): 8 inches -- Total Weight: 35 lbs - Total Weight: 135 lbs	
2.4.4 Ground Vehicle Avionics - Power: 0.72hp - 8 batteries -- 25.2 V, 41 Ahr -- 16,17 lbs		
2.6 Avionics/ Flight Controls	2.7 Aerial Vehicle	

- Three categories: -- Electronics for ground vehicle -- Avionics for air vehicle -- Electronics for ground station	- Both aerial and ground vehicle capable of internal sensing, navigation and communications.	
2.6.1 Avionics (Air)	2.7.1 Aerial Vehicle - GPS - LOS radio - BLOS satellite relay capability - Vision based terrain following system - Short range communication between aerial/ground vehicle - Standard RS-232 and MIL-1553B interfaces	

2.6.1.1 CPU (Central Processing Unit) - MACC (Multi-Application Control Computer) -- Monitored and controlled by ground station -- Capable of processing inputs from 50,000 sensor sets -- Flight control -- Vehicle Management system control -- Actuator/subsystem control	2.7.1.1 Avionics and Navigation - Three main computers -- MIAG -- RVM -- Flight Computer - Flight Computer: control center for all communication and navigation - MIAG (Modular Intregrated Avionics Group) -- heart of avionics system -- DGPS -- fiber optic inertial measurement unit -- air data pressure transducers -- IFF transponder - RVM (Reconfigurable Vision Machine). Vision based terrain following system. - MicroSTAR FLIR: uses dual imaging sensors. -- high resolution IR. -- boresighted CCD-TV with low-light capability.	

2.6.1.2. MIAG -See Section 2.7.1.1 of IPT 2 2.6.1.3 Radio - With ground vehicle - BLOS satellite 2.6.1.4 Encrytion 2.6.1.5 Weather: Detection capability	2.7.1.2 Sensing and Communications - Chemical and biological agent detection package. - CDL (Common Data Link): LOS (CDL Class 1) and BLOS (Class IV and V) communications	
2.6.2 Electronics (ground vehicle) 2.6.2.2 CPU 2.6.2.3 GPS 2.6.2.4 Radio: Same as air vehicle 2.6.2.5 Encryption 2.6.2.6 FLIR: Ultra 7500 FLIR system produced by FLIR Systems, Inc. 2.6.2.7 Chemical: minute acoustic wave sensors being developed by Sandia National Laboratory	2.7.2 Ground Vehicle - GPS -- Navigation - Chemical and Biological detection -- Sandia National Laboratory Lab-On-A-Chip - Video relay -- Small Camera: Visible or IR - Communication with aerial vehicle. - General Pupose CPU	

2.6.3 Ground Station - Communicates with vehicle during mission - Components: -- Laptop computer interface -- Encryption device -- Satellite Radio -- Serial Port interface for direct information transfer with vehicle before and after mission. - Following windows: 2.6.3.1 Terrain 2.6.3.2 Vision 2.6.3.3 Status 2.6.3.4 Weather 2.6.3.5 Chemical 2.6.3.6 Threat 2.6.3.7 Mission		

2.6.4 Software (Programs) 2.6.4.1 Air Vehicle - Control - Destination - Obstacle Avoidance - Weather Detector - Mission Profile 2.6.4.2 Ground Vehicle - Control - Enemy Recognition - Destination - Obstacle Avoidance - Chemical Detection 2.6.4.3 Ground Station - Visual Mapping - User Friendly Interface - Map Database - System Diagnostics		

APPENDIX G WEB PAGES

Copies of web pages referenced in this volume are located on the "Unmanned Hybrid Vehicle" CD that was provided as a supplement to the deliverables.